

ANNUAL REPORT OF THE
BOARD OF REGENTS OF
THE SMITHSONIAN
INSTITUTION

SHOWING THE

OPERATIONS, EXPENDITURES, AND
CONDITION OF THE INSTITUTION
FOR THE YEAR ENDING JUNE 30

1918



(Publication 2549)

WASHINGTON
GOVERNMENT PRINTING OFFICE

1920

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
75 CENTS PER COPY

∇

LETTER
FROM THE
SECRETARY OF THE SMITHSONIAN INSTITUTION,
SUBMITTING
THE ANNUAL REPORT OF THE BOARD OF REGENTS OF THE
INSTITUTION FOR THE YEAR ENDING JUNE 30, 1918.

SMITHSONIAN INSTITUTION,
Washington, August 29, 1919.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, in behalf of the Board of Regents, to submit to Congress the annual report of the operations, expenditures, and condition of the Smithsonian Institution for the year ending June 30, 1918. I have the honor to be,

Very respectfully, your obedient servant,

CHARLES D. WALCOTT, *Secretary.*

CONTENTS.

	Page.
Letter from the Secretary submitting the annual report of the Regents to Congress	III
Contents of the report	V
List of plates	VII
General subjects of the annual report	IX
Officials of the institution and its branches	XI
REPORT OF THE SECRETARY.	
The Smithsonian Institution	1
The Establishment	1
The Board of Regents	1
General considerations	2
Finances	4
Researches and explorations:	
Geological explorations in the Rocky Mountains	5
Researches on the structure of trilobites	7
Geological work in the Appalachian and Ohio Valleys	7
Geological work in Maryland	7
Geological work in Central Kentucky	8
Grasses of the Adirondack and White Mountains	9
Anthropological studies on Old American Families	10
The mountaineers of Tennessee	10
The vanishing Indian	11
Ethnological explorations in Colorado and Utah	12
National Parks Educational Committee	13
Publications	15
Library	16
National Museum	16
Bureau of American Ethnology	19
National Zoological Park	19
Astrophysical Observatory	20
International Exchanges	22
International Catalogue of Scientific Literature	22
Necrology	23
Appendix 1. Report on the United States National Museum	25
2. Report on the Bureau of American Ethnology	43
3. Report on the International Exchanges	58
4. Report on the National Zoological Park	66
5. Report on the Astrophysical Observatory	82
6. Report on the library	89
7. Report on the International Catalogue of Scientific Literature	94
8. Report on publications	97
EXECUTIVE COMMITTEE AND REGENTS.	
Report of Executive Committee	103
Proceedings of Board of Regents	107

GENERAL APPENDIX.		Page.
1. The Discovery of Helium, and What Came of It, by C. G. Abbot.....		121
2. An Account of the Rise of Navigation, by R. H. Curtiss.....		127
3. The Tornadoes of the United States, by Prof. Robert DeC. Ward.....		139
4. Wind Power, by James Carlill.....		147
5. A Tribute. Samuel Pierpont Langley: Pioneer in Practical Aviation, by Henry Leffman.....		157
6. Twentieth Century Physics, by R. A. Millikan.....		169
7. The Experiments of Dr. P. W. Bridgman on the Properties of Mat- ter When Under High Pressure. Introductory Note by C. G. Abbot		185
8. The Problem of Radioactive Lead, by Theodore W. Richards.....		205
9. Sphagnum Moss: War Substitute for Cotton in Absorbent Dress- ings, by Prof. George E. Nichols.....		221
10. History of Military Medicine and its Contributions to Science, by Col. W. P. Chamberlain.....		235
11. Some problems of International Readjustment of Mineral Supplies as Indicated in Recent Foreign Literature, by Eleanor F. Bliss.....		251
12. Reptile Reconstructions in the United States National Museum, by Charles W. Gilmore.....		271
13. A Pleistocene Cave Deposit in Western Maryland, by J. W. Gidley....		281
14. Paleobotany: A Sketch of the Origin and Evolution of Floras, by Edward W. Berry.....		289
15. The Direct Action of Environment and Evolution, by Prince Kropotkin..		409
16. The Law of Irreversible Evolution, by Branislav Petronievics.....		429
17. The Fundamental Factor of Insect Evolution, by S. S. Chetverikov....		441
18. The Psychic Life of Insects, by E. L. Bouvier.....		451
19. Sexual Selection and Bird Song, by Chauncey J. Hawkins.....		461
20. Marine Camoufleurs and Their Camouflage: The Present and Pros- pective Significance of Facts Regarding the Coloration of Tropical Fishes, by W. H. Longley.....		475
21. Foot-Plow Agriculture in Peru, by O. F. Cook.....		487
22. Sun Worship of the Hopi Indians, by J. Walter Fewkes.....		493
23. A Constitutional League of Peace in the Stone Age of America: The League of the Iroquois and Its Constitution, by J. N. B. Hewitt.....		527
24. The Problem of Degeneracy, by H. F. Tredgold.....		547
25. History in Tools, by W. M. Flinders Petrie.....		563
26. The Background of Totemism, by E. Washburn Hopkins.....		573
27. A Great Naturalist: Sir Joseph Hooker, by Sir E. Ray Lankester.....		585

LIST OF PLATES.

Tornadoes (Ward) :	Page.	Paleobotany (Berry)—Contd.	Page.
Plate 1.....	140	Plate 3.....	342
Langley (Leffmann) :		Plate 4.....	378
Plate 1.....	157	Plate 5.....	382
Plates 2, 3.....	158	Plate 6.....	402
Plates 4, 5.....	162	Insect Evolution (Chetverikov) :	
Plates 6, 7.....	164	Plate 1.....	446
Plates 8, 9.....	166	Marine Camouffleurs (Longley) :	
High Pressure (Bridgman) :		Plates 1-5.....	486
Plate 1.....	188	Foot Plow (Cook) :	
Sphagnum (Nichols) :		Plates 1-4.....	492
Plate 1.....	224	Sun Worship (Fewkes) :	
Plate 2.....	230	Plate 1.....	498
Plate 3.....	232	Plate 2.....	502
Plate 4.....	234	Plate 3.....	506
Reptile Reconstruction (Gilmore) :		Plate 4.....	508
Plates 1-6.....	280	Plate 5.....	510
Cave Deposit (Gidley) :		Plate 6.....	512
Plates 1-6.....	288	Plate 7.....	514
Paleobotany (Berry) :		Plate 8.....	518
Plate 1.....	334	Plate 9.....	520
Plate 2.....	338	Plate 10.....	522
		Plate 11.....	524

ANNUAL REPORT OF THE BOARD OF REGENTS OF THE SMITHSONIAN
INSTITUTION FOR THE YEAR ENDING JUNE 30, 1918.

SUBJECTS.

1. Annual report of the secretary, giving an account of the operations and condition of the Institution for the year ending June 30, 1918, with statistics of exchanges, etc.
2. Report of the executive committee of the Board of Regents, exhibiting the financial affairs of the Institution, including a statement of the Smithsonian fund, and receipts and expenditures for the year ending June 30, 1918.
3. Proceedings of the Board of Regents for the fiscal year ending June 30, 1918.
4. General appendix, comprising a selection of miscellaneous memoirs of interest to collaborators and correspondents of the Institution, teachers, and others engaged in the promotion of knowledge. These memoirs relate chiefly to the calendar year 1918.

THE SMITHSONIAN INSTITUTION.

June 30, 1918.

Presiding officer ex officio.—WOODROW WILSON, President of the United States.

Chancellor.—EDWARD DOUGLASS WHITE, Chief Justice of the United States.

Members of the Institution:

WOODROW WILSON, President of the United States.

THOMAS R. MARSHALL, Vice President of the United States.

EDWARD DOUGLASS WHITE, Chief Justice of the United States.

ROBERT LANSING, Secretary of State.

WILLIAM GIBBS MCADOO, Secretary of the Treasury.

NEWTON DIEHL BAKER, Secretary of War.

THOMAS WATT GREGORY, Attorney General.

ALBERT SIDNEY BUBLESON, Postmaster General.

JOSEPHUS DANIELS, Secretary of the Navy.

FRANKLIN KNIGHT LANE, Secretary of the Interior.

DAVID FRANKLIN HOUSTON, Secretary of Agriculture.

WILLIAM COX REDFIELD, Secretary of Commerce.

WILLIAM BAUCHOP WILSON, Secretary of Labor.

Regents of the Institution:

EDWARD DOUGLASS WHITE, Chief Justice of the United States, Chancellor.

THOMAS R. MARSHALL, Vice President of the United States.

HENRY CABOT LODGE, Member of the Senate.

CHARLES S. THOMAS, Member of the Senate.

HENRY FRENCH HOLLIS, Member of the Senate.

SCOTT FERRIS, Member of the House of Representatives.

LEMUEL P. PADGETT, Member of the House of Representatives.

FRANK L. GREENE, Member of the House of Representatives.

ALEXANDER GRAHAM BELL, citizen of Washington, D. C.

GEORGE GRAY, citizen of Delaware.

CHARLES F. CHOATE, Jr., citizen of Massachusetts.

JOHN B. HENDERSON, Jr., citizen of Washington, D. C.

HENRY WHITE, citizen of Maryland.

Executive committee.—GEORGE GRAY, ALEXANDER GRAHAM BELL, ERNEST W.

ROBERTS.

Secretary of the Institution. CHARLES D. WALCOTT.

Assistant Secretary.—RICHARD RATHBUN.

Chief Clerk.—HARRY W. DORSEY.

Accountant and disbursing agent.—W. I. ADAMS.

Editor.—A. HOWARD CLARK.

Assistant Librarian.—PAUL BROCKETT.

Property clerk.—J. H. HILL.

THE NATIONAL MUSEUM.

Keeper ex officio.—CHARLES D. WALCOTT, Secretary of the Smithsonian Institution.

Assistant secretary in charge.—RICHARD RATHBUN.

Administrative assistant.—W. DE C. RAVENEL.

Head curators.—WILLIAM H. HOLMES, LEONHARD STEJNEGER, G. P. MERRILL.

Curators.—PAUL BARTSCH, R. S. BASSLER, T. T. BELOTE, A. HOWARD CLARK, F. W. CLARKE, F. V. COVILLE, W. H. DALL, CHESTER G. GILBERT, WALTER HOUGH, L. O. HOWARD, ALEŠ HRDLÍČKA, FREDERICK L. LEWTON, GEORGE C. MAYNARD, GERRIT S. MILLER, Jr., ROBERT RIDGWAY.

Associate curators.—J. C. CRAWFORD, C. W. GILMORE, W. R. MAXON, J. N. ROSE, DAVID WHITE.

Curator, National Gallery of Art.—W. H. HOLMES.

Chief of correspondence and documents.—H. S. BRYANT.

Disbursing agent.—W. I. ADAMS.

Chief of exhibits (Biology).—JAMES E. BENEDICT.

Superintendent of buildings and labor.—J. S. GOLDSMITH.

Editor.—MARCUS BENJAMIN.

Assistant librarian.—N. P. SCUDDER.

Photographer.—L. W. BEESON.

Registrar.—S. C. BROWN.

Property clerk.—W. A. KNOWLES.

Engineer.—C. R. DENMARK.

BUREAU OF AMERICAN ETHNOLOGY.

Chief.—J. WALTER FEWKES.

Ethnologists.—JOHN P. HARRINGTON, J. N. B. HEWITT, FRANCIS LA FLESCHÉ, TRUMAN MICHELSON, JAMES MOONEY, JOHN R. SWANTON.

Honorary philologist.—FRANZ BOAS.

Editor.—STANLEY SEARLES.

Librarian.—ELLA LEARY.

Illustrator.—DE LANCEY GILL.

INTERNATIONAL EXCHANGES.

Chief clerk.—C. W. SHOEMAKER.

NATIONAL ZOOLOGICAL PARK.

Superintendent.—NED HOLLISTER.

Assistant Superintendent.—A. B. BAKER.

ASTROPHYSICAL OBSERVATORY.

Director.—C. G. ABBOT.

Aid.—F. E. FOWLE, Jr.

Assistant.—L. B. ALDRICH.

REGIONAL BUREAU FOR THE UNITED STATES, INTERNATIONAL
CATALOGUE OF SCIENTIFIC LITERATURE.

Assistant in charge.—LEONARD C. GUNNELL.

REPORT
OF THE
SECRETARY OF THE SMITHSONIAN INSTITUTION

CHARLES D. WALCOTT

FOR THE YEAR ENDING JUNE 30, 1918.

To the Board of Regents of the Smithsonian Institution.

GENTLEMEN: I have the honor to submit herewith the customary annual report by the secretary on the present condition and the operations and activities of the Institution and its branches during the year ending June 30, 1918. The first portion of the report is devoted to the Institution proper and the summaries of the work of the National Museum and other branches, while the appendices give detailed accounts by those in direct charge of the activities of the Museum, the Bureau of Ethnology, the International Exchanges, the Zoological Park, the Astrophysical Observatory, the Library, and the Catalogue of Scientific Literature.

THE SMITHSONIAN INSTITUTION.

THE ESTABLISHMENT.

The Institution was created an establishment by act of Congress approved August 10, 1846. Its statutory members are the President of the United States, the Vice President, the Chief Justice, and the heads of the executive departments.

THE BOARD OF REGENTS.

The Board of Regents, which is charged with the administration of the Institution, consists of the Vice President and the Chief Justice of the United States as ex officio members, three Members of the Senate, three Members of the House of Representatives, and six citizens, "two of whom shall be residents of the city of Washington and the other four shall be inhabitants of some State, but no two of them from the same State."

There were changes in the personnel of the board during the year, as follows: Senator Charles S. Thomas to succeed Senator William J. Stone, died April 14, 1918; Representatives Lemuel P. Padgett

and Frank L. Greene to succeed Ernest W. Roberts and James T. Lloyd whose terms expired December 26, 1917. The roll of regents on June 30, 1918, was as follows: Edward D. White, Chief Justice of the United States, Chancellor; Thomas R. Marshall, Vice President of the United States; Henry Cabot Lodge, Member of the Senate; Charles S. Thomas, Member of the Senate; Henry French Hollis, Member of the Senate; Scott Ferris, Member of the House of Representatives; Lemuel P. Padgett, Member of the House of Representatives; Frank L. Greene, Member of the House of Representatives; Alexander Graham Bell, citizen of Washington, D. C.; George Gray, citizen of Delaware; Charles F. Choate, jr., citizen of Massachusetts; John B. Henderson, citizen of Washington, D. C. (Charles W. Fairbanks, of Indiana, died June 4, 1918, vacancy not filled at close of fiscal year); and Henry White, citizen of Maryland.

The board held its annual meeting on December 13, 1917. Mr. Henry White was elected a member of the executive committee to fill the vacancy caused by the resignation of Mr. Ernest W. Roberts, whose term of office would expire on December 26, 1917. The proceedings of that meeting, as also the annual financial report of the executive committee, have been printed, as usual, for the use of the regents, while such important matters acted upon as are of public interest are reviewed under appropriate heads in the present report of the secretary. A detailed statement of disbursements from the Government appropriations under the direction of the Institution for the maintenance of the National Museum, the National Zoological Park, and other branches will be submitted to Congress by the secretary in the usual manner in compliance with the law.

GENERAL CONSIDERATIONS.

The routine operations of the Institution and its branches were carried on as usual during the year, but a number of activities were held in abeyance until after the war. The time and energy of members of the scientific staff were devoted, as far as practicable, to researches bearing on the effectiveness of certain devices and materials for the Army and Navy, and 24 employees were granted furloughs to enter active military service.

Through my connection with the National Research Council and other commissions and boards I have been able personally to render some war service to the Government.

The work of the National Advisory Committee for Aeronautics, of which the secretary of the Institution is a member and chairman of the executive committee, has greatly broadened. At its suggestion the Council of National Defense appointed a committee, now known as the Aircraft Board, to consider all questions of aircraft production and to make recommendations to the military departments for

the production and purchase of aircraft and aircraft appliances. The experimental laboratory of the advisory committee has been erected at Langley Field, near Hampton, Va.

The original Langley man-carrying flying machine has been brought back from Hammondsport, after several successful flights, and is exhibited in the National Museum. This is the first heavier-than-air man-carrying machine built, although it did not have a successful flight until more than 10 years after its construction. It is also an important historical relic, as it confirms the claim that Secretary Langley was the first to design and construct a heavier-than-air machine capable of carrying a man in flight. There has never been any question that he was the first to successfully fly a heavier-than-air machine propelled by its own power.

In February the War Department allotted to the Smithsonian Institution the sum of \$10,000 for experimental work in aviation in connection with the Signal Corps, which work is being successfully carried on. Upon the invitation of the War Industries Board, Mr. C. G. Gilbert, of the National Museum, was appointed a member of the Joint Information Board of Minerals and Derivatives, in which capacity he has done work of unusual value. In April the Secretary offered to the Government the services of Dr. Aleš Hrdlička, who has since prepared important reports upon ethnography for the National Research Council and for a congressional committee of investigation into the effect of language on nationality.

The Smithsonian chapter of the Red Cross has done commendable war work. Early in the year an ambulance was given for service in Russia and later the funds were raised to defray for one year the expenses incidental to the maintenance of a bed in the American Red Cross Hospital at Neuilly.

Bequests.—Among the bequests to the Museum during the past year is that of Miss S. J. Farmer, who willed to the Museum all the remaining models of her father, Moses G. Farmer, inventor of electrical apparatus.

The Institution has been made the residuary legatee of the estate of Rev. Bruce Hughes, of Philipsburg, Pa. (died March 20, 1916), under the following terms of his will probated March 27, 1916:

All the balance and residue of my estate of which I may die seized shall be paid to the Smithsonian Institute of the city of Washington, District of Columbia, the sum to be invested and the income alone used to found the Hughes Alcove of the said Smithsonian Institute.

The final share of the Institution in the estate has been estimated at about \$11,500. It is proposed that the "alcove" referred to in the will shall be established in and as a part of the National Gallery of Art and that the fund be devoted to the amassing of a reference library of art works.

Gifts.—Dr. Frank Springer has given the Institution the title and custody in perpetuity of his large collection of fossil crinoids and related groups of Echinoderms and has arranged for a fund of \$30,000, the income of which is to be devoted to the administration of the collection.

Dr. W. L. Abbott has continued his generous gifts of collections and his support of an expedition in Celebes under H. C. Raven.

FINANCES.

The invested funds of the Institution consist of the following:

Deposited in the Treasury of the United States under authority of Congress.....	\$1,000,000.00
---	----------------

CONSOLIDATED FUND.

Brooklyn Rapid Transit 5 per cent notes due July 1, 1918, cost....	\$5,040.63
Province of Manitoba 5 per cent gold debentures due April 1, 1922, cost.....	1,935.00
American Telephone and Telegraph Company 4 per cent collateral trust bonds due July 1, 1929, cost.....	15,680.00
West Shore Railroad Co. guaranteed 4 per cent first mortgage bonds due January 1, 1931, market value.....	37,275.00
	59,930.63
Excess cost of bonds redeemed at par.....	93.75
Total.....	1,060,024.38

The combined interest-bearing investments, aggregating \$1,060,024.38, are represented by the following funds:

Smithson fund	\$728,291.00
Habel fund	500.00
Hamilton fund.....	2,500.00
Hodgkins general fund.....	153,275.00
Hodgkins specific fund.....	100,000.00
Rhees fund	627.00
Avery fund	24,020.38
Addison T. Reid fund.....	11,672.00
Lucy T. and George W. Poore fund.....	27,965.00
George K. Sanford fund.....	1,174.00
Chamberlain fund	10,000.00
Total.....	1,060,024.38

One piece of improved real estate in the District of Columbia, bequeathed to the Institution by the late Robert Stanton Avery, was sold during the year; the net amount realized from this sale was \$8,721, which amount has been invested in bonds forming a part of the Consolidated Fund.

The practice of investing surplus funds in certificates of deposit paying 3 per cent per annum has proved most satisfactory; the income from this source amounting to \$1,275 during the year.

Instead of investing all surplus cash in certificates of deposit, the Institution purchased \$10,000 of the United States Third Liberty Loan, which will be carried on the books temporarily as a special asset and later will be transferred to the Consolidated Fund.

The income of the Institution during the year, amounting to \$165,135.02, was derived as follows: Interest on permanent investments and other sources, \$63,552.02; repayments, rentals, publications, etc., \$13,503.13; contributions from various sources for specific purposes, \$24,358.87; bills receivable, \$55,000; proceeds from sale of real estate, \$8,721.

Adding the cash balance of \$9,232.56 on July 1, 1917, the total resources for the fiscal year amounted to \$174,367.58.

The disbursements, which are given in detail in the annual report of the executive committee, amounted to \$173,077.68, leaving a balance of \$1,289.90 in cash and on deposit in the Treasury of the United States and in bank.

In addition to the above disbursements by the Institution, there was included under the general appropriation for printing and binding an allotment of \$76,200 to cover the cost of printing and binding the Smithsonian annual report and reports and miscellaneous printing for the Government branches of the Institution.

The Institution was charged by Congress with the disbursement of the following appropriations for the year ended June 30, 1918:

International exchanges	\$35,000.00
American ethnology	42,000.00
International catalogue of scientific literature.....	7,500.00
Astrophysical observatory	13,000.00
Observations, eclipse of the sun of June 8, 1918.....	2,000.00
National Museum:	
Furniture and fixtures.....	25,000.00
Heating and lighting.....	46,000.00
Preservation of collections.....	300,000.00
Building repairs	10,000.00
Books	2,000.00
Postage	500.00
National Zoological Park.....	100,000.00
Increase of compensation (indefinite).....	
Total	583,000.00

RESEARCHES AND EXPLORATIONS.

The researches and explorations by the Institution were greatly limited in their scope during the past year on account of war conditions. There was unusual activity, however, by members of the scientific staff in investigations which related to the operations of the Army and Navy, and it is believed that the results have been of great benefit to the service.

Several biological and ethnological expeditions to various parts of the world have been held in abeyance, although some already in the field have continued in operation on a limited scale. It is expected that after the war there will be greater activity in these lines than ever before.

Accounts of some of the more important researches are given here and others are reported upon in the Appendix.

GEOLOGICAL WORK IN THE ROCKY MOUNTAINS.

Geological field work has been carried on by me in the Rocky Mountains for several years past, particularly in the study of Cambrian and pre-Cambrian formations. The more important results of this work have been described in my paper on "Evidences of Primitive Life" in the Smithsonian Report for 1915 and in various pamphlets of the Institution. Investigations during the summer and early fall of 1917 were carried on at the now well-known "Burgess Pass" fossil quarry, discovered by me in 1910. Fifty days were spent at the Burgess Pass camp, 3,000 feet above Field, British Columbia, where a section in the quarry of about 180 square feet was taken out. This practically exhausts a quarry which has given the finest and largest series of Middle Cambrian fossils yet discovered and the finest invertebrate fossils yet found in any formation in any country. More than one and a half tons of specimens were trimmed out at the quarry, carried by pack horses to camp, and thence by rail to Washington.

A few days were taken to verify a geologic section near Lake McArthur, and then the Vermilion River trip was begun. Following down the Bow River, we crossed to the south side near Mount Castle and camped at Vermilion Pass. Lower down the valley on the eastern side near the mouth of Ochre Creek, Syncline Peak shows remnants of the compression and folding that accompanied the uplift of the mountain massif, now cut by erosion into hundreds of mountains, ridges, and canyons.

From Vermilion River the party followed a new forest ranger trail up Tumbling Brook to a small, beautiful glacier beneath the great eastward facing cliffs of Gray Peak.

Wolverine Pass is a broad, rolling area at about timber line. On its southwestern slope the northeast branch of Moose Creek begins, on the north slope the headwaters of Ochre Creek, and on the southeast the drainage is to Tumbling Brook, a branch of Ochre Creek. The views from the upper slopes northeast of the Pass are among the finest in the Canadian Rockies. Mount Drysdale, on the right, rises 2,200 feet above the Pass, and Mount Gray, on the left, 1,800 feet, the altitude of the Pass being 7,200 feet. Tumbling Glacier, on the left of Mount Gray, is formed from snows blown over the

cliffs from the westward. On the right of Mount Drysdale the eastern side of the great Washmawapta snow field may be seen; in the distance, through the Pass, the dark Beaverfoot Range, and beyond it, in the extreme background, the snowy peaks of the Selkirk Ranges.

A late September storm drove us back from Wolverine Pass to the Vermilion River, where below Ochre Creek a search was made for moose. On October 1 a great bull, a cow, and young were brought down and their skins, skulls, and horns secured for the National Museum collections.

RESEARCHES ON THE STRUCTURE OF THE TRILOBITES.

In my laboratory work for the past 45 years I have been on the watch for evidence bearing on the structure and organization of fossil trilobites. The study of a small and unique series of specimens secured at Burgess Pass since 1910 has so greatly increased our knowledge of these interesting animals that a special paper, accompanied by 28 plates of illustrations, is now in press, to appear in the Smithsonian Miscellaneous Collections.

GEOLOGICAL WORK IN THE APPALACHIAN AND OHIO VALLEYS.

During the summers of 1916 and 1917 Mr. Frank Springer continued his researches upon the fossil echinoderms of the Ohio Valley with a view to obtaining further material and information for the completion of a monograph upon the Silurian crinoids of that area which he has now in preparation. His assistant, Dr. Herrick E. Wilson, collected in the vicinity of St. Paul and of Madison, in Indiana, proving for the first time the presence in the latter locality of the crinoidal faunas of both the Waldron and the Laurel formations. One object of the present field investigation is to obtain further light on the relations of the Silurian faunas of the Chicago and southern Indiana areas with those of western Tennessee. Mr. Springer acquired by purchase all the echinoderms in the large collection of Mr. John F. Hammell, of Madison, Ind., which included that made by A. C. Benedict from the Indiana Silurian, containing the types of a considerable number of species. This material has been added to his collection of fossil echinoderms now deposited in the National Museum.

GEOLOGICAL WORK IN MARYLAND.

Dr. Bassler, of the division of invertebrate paleontology in the National Museum, reports that, in company with Assistant Curator Dr. C. E. Resser, he made some investigations in the Frederick and Hagerstown valleys of Maryland with the object of securing for the exhibition series large examples illustrating the various types of conglomerate. Two fine, large masses of the well-known Triassic

limestone conglomerate were obtained with little difficulty, but equally good examples of the siliceous variety were secured only after much hard labor, owing to the ready disintegration of the rock on exposure. Efforts were finally successful, however, and there was also secured a mass of the so-called "edgewise" conglomerate several feet in diameter, which will well illustrate the phenomenon of intraformation conglomerate described by me a number of years ago. This last was obtained where the steeply dipping lower Ordovician beds outcropped in such a manner that the desired material could be blasted without fracturing. All of such conglomerates are the result of ancient mud deposits of tidal flats becoming sun cracked when exposed to the air. The dried edges of the sun-cracked areas become tossed about by the wind and the fragments finally accumulate in layers which ultimately are hardened into rocklike conglomerate. Conglomerates usually indicate the base of a formation, but this particular kind may occur at any place within a formation, whence I applied the specific name "intraformational" to them.

GEOLOGICAL WORK IN CENTRAL KENTUCKY.

After the conclusion of geologic work in the Appalachian Valley in the early summer of 1917, Dr. Bassler proceeded to central Kentucky, where he spent several weeks in explorations for suitable exhibition specimens covering the general subject of stratigraphic paleontology. It was especially desirable that such phenomena as stratification, the occurrence of fossils, and unconformities should be illustrated in the Museum, and especial efforts were made to secure specimens exhibiting these features. Much discrimination was necessary in the selection of these objects, as it was essential to obtain specimens of such size as to be appreciated by the public and still not too large for the available space, which is somewhat limited. This difficulty complicated the work, but the selection finally made was extremely satisfactory. In his account of the work Dr. Bassler says:

The early Paleozoic coral reef near Louisville, Ky., from which a section 6 by 10 feet in dimensions had been quarried and placed on exhibition during the summer of 1916, was revisited and several additional layers of highly fossiliferous shale and limestone were secured. These have now been added in their proper position to the coral-reef mount, so that this single exhibit now illustrates the subjects of stratification in general, horizontal strata, change of lithology from limestone to shale, the occurrence of fossils in these types of sediment, and the phenomenon of fossil coral reefs for which the exhibit was primarily planned.

The most valuable result of the summer's work was achieved at Elkin, Ky. Here a single limestone slab, 6 feet long and several feet wide and thick, showing an unconformity distinct enough to be appreciated by the layman, was quarried out and shipped to the museum without breakage, where it now forms a most instructive exhibit. The outcropping limestone ledge, several feet in thickness, is composed of a distinctly white lower portion and a dark-colored

upper part, the head of the hammer marking their line of contact. This line also marks an unusually clear unconformity. Both of these layers are rich in fossils, those of Early Black River (Lowville) age occurring in the lower white rock and those of Early Trenton in the upper dark material. Since at other places in the United States 500 or more feet of strata of Middle and Late Black River age intervene between these two layers, it is shown that Kentucky was a land area during the deposition of the Middle and Upper Black River strata. This is also evidenced by numerous worm burrows extending downward from the top of the white limestone. When the material was in the condition of soft mud and exposed at the surface, the worms burrowed into it, as they do in the soil to-day.

The phosphate localities near Wallace, Ky., were next visited, in order to obtain illustrations of the gradual phosphatization of limestone and the types of fossils in phosphatic strata. Here it was discovered that phosphate rock occurs only along the joint planes of the limestone. Surface water passing along these joint planes leaches out the calcium carbonate of the phosphatic limestone, leaving the calcium phosphate content behind.

GRASSES OF THE ADIRONDACK AND WHITE MOUNTAINS.

During the month of August, 1917, Mr. A. S. Hitchcock, systematic agrostologist in the Department of Agriculture and custodian of the section of grasses of the division of plants in the United States National Museum, visited the Adirondacks in New York and the White Mountains in New Hampshire for the purpose of studying their flora, especially the grasses of the alpine summits. Mr. Hitchcock reports as follows:

In the Adirondacks headquarters were at Lake Placid, from which point excursions were made to the summits of Whiteface and McIntyre, the highest peaks in the group with the exception of Mount Marcy. It was impracticable to reach Mount Marcy without the use of a camp outfit. This peak rises to a height of 5,344 feet, but Mount McIntyre is nearly as high (5,112 feet). Both McIntyre and Whiteface extend above the timber line and support at the summit an alpine flora.

The White Mountains reach a somewhat greater altitude than the Adirondacks, Mount Washington, the highest peak, being 6,293 feet. In the Mount Washington group there are several peaks whose summits are above the timber line. The alpine flora of these peaks and of the peaks of the Adirondacks are similar, and include plants that farther north are found at a lower altitude or, in the Arctic regions, even at sea level.

Four days were spent investigating the flora of the peaks. The ascent was commenced at Crystal Cascade on the east side, whence the trail led up Tuckerman Ravine to the Summit of Mount Washington, thence down to Lakes-of-the-Clouds where there is an Appalachian Mountain Club hut for the accommodation of climbers. From here the head of Oakes Gulf was explored. The second day was spent along the trail from Lakes-of-the-Clouds to the Mount Madison hut, going by the way of the Westside and Gulfside trail, which passes near the high peaks of Clay, Jefferson, and Adams. The return trip to Lakes-of-the-Clouds hut was made on the third day, descending 3,000 feet through the Great Gulf by the Buttress trail and ascending again by the Six Husbands trail to the Alpine Meadow. On the fourth day the descent was made by way of Huntington Ravine over a little-used and difficult trail.

There are nine species of grasses that may be considered to be alpine. A few others extend from the lower zones into the alpine region. Most of the alpine species are circumpolar and extend southward in the mountains, one to the high peaks of western North Carolina and two through the Rocky Mountains even in South America. One species, *Poa laxa*, is abundant on the upper cone of Mount Washington, extending quite to the summit, and comprises almost the only vegetation of this area. This is a European species which is found in North America only in the region of Mount Washington and on a few of the higher peaks of New England.

The forest flora of the mountains consists mainly of white pine, white spruce, larch, aspen, and white birch. Toward the summits of the peaks the dominant tree is the balsam fir, which near timber line becomes a straggling shrub.

ANTHROPOLOGICAL STUDIES ON OLD AMERICAN FAMILIES.

In continuation of his researches on old American families, Dr. Hrdlička, of the National Museum, in 1917, visited Yale, Virginia, and Harvard Universities. The last two were visited on the occasion of the "Teachers' Course," which brings to these institutions many adult individuals of old American parentage from a large territory. The total number of subjects examined, mainly for pigmentation of hair, and eye and skin color, amounted to over 1,000, all of whom were Americans of at least three generations on both the paternal and maternal sides of the family. Dr. Hrdlička says:

The results which are now being elaborated for a report are of uncommon interest. They show a number of important facts of which we had no previous reliable knowledge. One of these is, in brief, that there is no increase in the proportion or grade of pigmentation as we proceed from New England southward, and no increase in blondness as we proceed northward from the Carolinas and Virginias. Another striking result shows that there are localized peculiarities in pigmentation, especially that of the hair, but that in every case these can be traced to the ancestry rather than to the environmental conditions. The latter nevertheless appear to have been active in general in reducing the total proportions of blondness.

So far as the color of the eyes is concerned there were found unexpectedly, in all the areas, a large proportion of "mixed" colors; in other words, eyes in which more or less marked traces of brown coexist with various shades of blue, green, or gray.

Three cases were encountered in which the color of the two eyes was markedly different. Pure beautiful blues and browns were few in number.

THE MOUNTAINEERS OF TENNESSEE.

During the latter part of July, 1917, Dr. Hrdlička made a trip to eastern Tennessee, for the purpose of becoming acquainted with the characteristics of the population of these regions, which in large part is of old American stock but has long existed under disadvantageous environment, remaining as a result backward in education and in other respects. He reports as follows on the results of his studies:

The work commenced at Bristol, Tenn., extended to Mountain City, and farther on into the hills; and its success was very largely due to the kind

offices and direct personal help of an old friend of the Smithsonian Institution, Mr. Samuel L. King, of Bristol. For additional help the writer is indebted to Mr. John Caldwell, of the same city.

The work extended mainly to the men called for examination by the first draft for the United States Army, and comprised 150 individuals. Both measurements and observations were taken. Some of the men came from the lower lands of the Bristol district and were kept apart, but a good number represented the real mountaineers.

It is too early to speak of the results of this interesting piece of research, the data not having as yet been properly reduced and analyzed; but it is safe to say that these mountaineers represent no separate type of Americans. In many cases they still show strong indications of their respective pre-American ancestry. Among the men there were seen some fine examples of physique—willowy, clean-cut six-footers; but there were also others of rather feeble mental powers or nervous stability, which conditions, to some extent possibly, are due to hereditary effects of alcoholism or to defective heredity of other nature.

The families of the mountaineers are remarkable in many cases for their large size, and there were seen examples of longevity and virility which it would be hard to find in our cities.

There are all grades of "mountaineers" and no line of demarcation separates them from the people in the lower lands, who are mostly of similar derivation and sometimes of the same families. But as one proceeds into the wilds of the mountains the population becomes sparser and more backward, the cultivated patches of ground smaller in area, and the habitations poorer, until some of the latter come to resemble the shacks of the southern negro.

The poorer class of mountaineers frequently show characteristics partly due to their backwardness in education and their isolation and partly, perhaps, to hookworm disease or other abnormal conditions. Some of the young men are types of slouchiness, such as would delight the artist, while the women disfigure themselves by chewing snuff and frequently show uncouthness in dress, movements, and behavior. But the people are hospitable and interesting. In the course of a short ride of less than 2 miles through a sparsely settled gorge the writer and his local companion had no less than four invitations to lunch—in the other places there was no one at home. Their language and intonation are characteristic and quaint, and the people seem to be full of old and local folklore, the study of which would probably prove most delightful. Being largely dependent on themselves and their few neighbors, they have also many antiquated and strange curative practices which would repay investigation.

Their worst enemies are the isolation, "moonshine" whisky, and, in not a few cases, undoubtedly a poor heredity. The Army draft will be a godsend to many of the young men, some of whom can not even read or write; but probably few of those who will return will remain mountaineers.

THE VANISHING INDIAN.

Through the cooperation of the Institution and the American Association for the Advancement of Science, Dr. Hrdlička in August, 1917, made some interesting investigations of the Shawnee and other Indian tribes. Concerning his work he says:

The progress of miscegenation among many of the Indian tribes has progressed to a degree that is surprising even to those who for many years have been studying the Indian. While the total number of "Indians" as recorded by the

census increases from decade to decade, the fact is that this increase is due wholly to that of mixed bloods; the full bloods of pure strain in most localities are rapidly disappearing and in a considerable proportion of the tribes have become actually extinct or are on the point of extinction.

Two remarkable examples of this fact have just been experienced by the writer. For years a growing necessity in American anthropology has been to determine the physical type of the Shawnee, once a large tribe and one of considerable historic importance. No great difficulty was apprehended in this task, as the tribe is still well represented. The most promising part of the tribe was that of the so-called "absentee" Shawnee, on the Shawnee Agency in eastern Oklahoma. They count 569 individuals, quite a few of whom are generally regarded as "full bloods." To his great disappointment the task of finding some pure bloods became exceedingly difficult. Quite a few of the Indians were found to be "full bloods," but on inquiry into the family history it was generally learned that the subject was a mixture of Shawnee with the Oneida, Delaware, Creeks, or some other tribe. In conclusion, there were found but three individuals who so far as they or their friends knew were full-blood Shawnee. Two of these were old women and one an old man, all near or over 70 years of age, and two of the three were sister and brother.

The next tribe visited was the Kickapoo, the main body of which to the number of 211 is settled about McLoud, Okla. They were said by the old Shawnee to be practically the same people as themselves, having at some time in the past had but one camp fire, and it was generally believed that they would show some full bloods of pure strain. This proved to be a vain hope. On close inquiry all sorts of mixtures were discovered, even among the oldest men and women of the tribe, but no pure bloods. Only one single woman of middle age was believed to be possibly a full Kickapoo, but there was no real certainty. Some visiting Kickapoo from Mexico proved no better than the rest, and no hope was given that any pure strain Kickapoo could be found anywhere else.

Thus two tribes, one of which of considerable importance, may be regarded as lost to science, so far as pure bloods are concerned. Only a few years ago, according to local information, there were still a number of old men and women living in both tribes who represented the pure strain. The genuine Indian is rapidly passing away and the work of the anthropologist who endeavors to record the physical type of the various tribes is becoming increasingly difficult.

ETHNOLOGICAL EXPLORATIONS IN COLORADO AND UTAH.

One of the most important results of field work by the Bureau of American Ethnology during the past year was the investigation of little-known towers, castles, and great houses in southwest Colorado. In conjunction with the Department of the Interior, the Smithsonian Institution has been engaged for a decade in the excavation and repair of large ruins situated on what is called the Mesa Verde National Park. The educational value of this work can hardly be overestimated, and in recent years over 2,500 people have visited the locality yearly to see these largest of all prehistoric ruins in our South-western States. In his field work during the summer of 1918 Dr. J. Walter Fewkes, Chief of the Bureau of American Ethnology, investigated equally instructive groups of ruins in the valleys in sight of the Mesa Verde Park and found there many well-preserved build-

ings of which little has been hitherto known; the most striking of these were finely constructed towers, castles, and great houses, the walls of which have fine masonry, rising in some instances 25 feet high. They may be instanced as the best-preserved examples of Indian stone houses north of Mexico. Three clusters of these remarkable constructions in southwestern Utah are specially noteworthy, containing in all 11 different buildings, the majority of which are still, after centuries of wear, in nearly the same condition as when deserted by the aboriginal builders. Many evidences of their prehistoric character were gathered. The name of the race to which their builders belonged is no longer known, but the memory of them still survives in dim legends of descendants living many miles away. A visit to these towers well supplements one to the Mesa Verde, and broadens one's knowledge of the variety of buildings which stood in the desert during the most flourishing epoch of North American architecture of the past. As a sequel to the explorations carried on by the Smithsonian in these remarkable monuments, the Director of the Public Park Service of the Department of the Interior, recognizing their educational value for scholars and tourists, has taken steps to have them set aside from the public domain and placed under the care of the Superintendent of the Mesa Verde Park for permanent preservation.

NATIONAL PARKS EDUCATIONAL COMMITTEE.

On June 26, 1918, at a meeting held at the Smithsonian Institution there was organized the National Parks Educational Committee. Dr. Charles D. Walcott, Secretary of the Smithsonian Institution, was chosen chairman, former Representative William Kent, of California, vice chairman, Henry B. F. Macfarland, of Washington, chairman of the executive committee, and Robert Sterling Yard, secretary. The membership includes representatives of universities, institutions, and public-spirited associations East and West, through whose cooperation it will present a front of many influential units.

The need of this organization grew out of the rapid growth of public interest in our national parks, due to the recent realization of their supreme qualities. It is a safe statement that there is no other cause so popular in America to-day that is not a war cause. The limitation of governmental functions practically to the physical development of the national parks leaves the gathering of their enormous potential harvests of education and appreciation to the people themselves; it is to organize these departments of higher enjoyment, to give impetus to the art and literature of outdoors, to popularize natural science, and to encourage outdoor living that the committee is established.

The committee will support a plan of systematic selection and development to secure for American national parks the recognized first place in world scenery, thus realizing their value as a national economic asset. Its educational plans are based upon views of national parks as popular classrooms and museums of nature. It will seek the cooperation of public schools and universities in the interpretation of natural scenery in terms of popular science. Among its first acts was the passage of a resolution, offered by Leonidas Dennis, of New Jersey, favoring the bill which has passed the Senate and is now before the House to make the Grand Canyon a national park.

The committee will enlarge itself so as to become representative of every section and State in the country. It is the initial stage in a broad national organization to be perfected after the war under the title of the National Parks Association. The members at present are as follows:

Wallace W. Atwood, department of physiography, Harvard University.

Arthur E. Bestor, president of Chatauqua Institution.

Belmore Browne, explorer, author, artist.

Henry G. Bryant, president Geographical Society of Philadelphia, explorer.

John B. Burnham, president American Game Protective and Propagation Association.

William E. Colby, president Sierra Club.

Leonidas Dennis, conservationist, lawyer.

J. Walter Fewkes, chief Bureau of American Ethnology.

John H. Finley, president University of State of New York.

William B. Greeley, chairman conservation committee Camp Fire Club.

George Bird Grinnell, Boone and Crockett Club, pioneer of Glacier National Park.

William H. Holmes, curator of National Gallery of Art, head curator anthropology, United States National Museum.

William Kent, former United States Representative, donor of the Muir Woods National Museum.

George F. Kunz, president of American Scenic and Historic Preservation Society.

E. M. Lehnerts, department of geology, University of Minnesota; pioneer in national parks geology classes.

Henry B. F. Macfarland, publicist; lawyer.

J. Horace McFarland, president American Civic Association.

La Verne Noyes, president board of trustees, Chicago Academy of Science.

George D. Pratt, conservation commissioner, State of New York; president Camp Fire Club.

D. W. Roper, director Prairie Club; engineer.

Edmund Seymour, president American Bison Society.

Charles Sheldon, Boone and Crockett Club; explorer, author.

Mrs. John Dickinson Sherman, conservation chairman, General Federation of Women's Clubs.

Charles D. Walcott, secretary Smithsonian Institution.

Robert Sterling Yard, Chief Educational Division, National Park Service.

PUBLICATIONS.

The Institution and its branches published during the year 91 volumes and separate pamphlets. The total distribution was 134,284 copies, which included 1,591 volumes and memoirs of Smithsonian Contributions to Knowledge, 26,412 volumes and separates of the Smithsonian Miscellaneous Collections, 19,815 Annual Reports and separate papers, 75,300 volumes and pamphlets of Museum Proceedings, 7,344 Bureau of American Ethnology publications, 2,929 special publications, and others relating to the Astrophysical Observatory, the Harriman Alaska Expedition, and the American Historical Association.

War conditions naturally greatly delayed the issuance of publications by the Government Printing Office, so that there is a large accumulation of material in proof and manuscript awaiting completion.

Allotments for printing.—The allotments for the printing of the Smithsonian Report and the various publications of the branches of the Institution were practically used up, a small balance remaining in one or two cases owing to the impossibility of getting certain publications off the press before the close of the year.

The allotments for the year ending June 30, 1919, are as follows:

For the Smithsonian Institution: For printing and binding the annual reports of the Board of Regents, with general appendices, the editions of which shall not exceed 10,000 copies.....	\$10,000
For the annual reports of the National Museum, with general appendices, and for printing labels and blanks, and for the bulletins and proceedings of the National Museum, the editions of which shall not exceed 4,000 copies, and binding, in half morocco or material not more expensive, scientific books, and pamphlets presented to or acquired by the National Museum library.....	37,500
For the annual reports and bulletins of the Bureau of American Ethnology and for miscellaneous printing and binding for the bureau....	21,000
For miscellaneous printing and binding:	
International Exchanges.....	200
International Catalogue of Scientific Literature.....	100
National Zoological Park.....	200
Astrophysical Observatory.....	200
For the annual report of the American Historical Association.....	7,000
Total.....	76,200

Committee on printing and publication.—The Smithsonian advisory committee on printing and publication considers all manuscripts offered for publication by the Institution or its branches. During the past year 13 meetings were held, at which 68 manuscripts were considered and acted upon. The membership of the committee is as follows: Dr. Leonhard Stejneger, head curator of biology, National Museum, chairman; Mr. N. Hollister, superintendent of the National Zoological Park; Mr. A. Howard Clark, editor of the

Institution, secretary of the committee; Dr. George P. Merrill, head curator of geology, National Museum; and Dr. J. Walter Fewkes, chief of the Bureau of American Ethnology, who succeeded Mr. F. W. Hodge, resigned.

LIBRARY.

The library of the Smithsonian Institution is divided into (1) the main library, consisting chiefly of journals and transactions of learned societies and institutions throughout the world, which are in the custody of the Library of Congress and administered as the Smithsonian deposit; (2) the National Museum library; (3) the library of the Bureau of American Ethnology; (4) the National Zoological Park library; (5) the library of the Astrophysical Observatory; and (6) the office reference library. Some of these are subdivided into several sectional libraries.

The report of the assistant librarian in the appendix presents details of accessions. Mention should here be made of one exceptional and important addition to the Museum library, consisting of a large number of botanical and horticultural publications brought together at Biltmore, N. C., by the late Mr. George W. Vanderbilt and presented by Mrs. Vanderbilt.

NATIONAL MUSEUM.

The detailed account of the operations of the National Museum is recorded in an appendix to this report by Mr. Ravenel, the administrative assistant who had chiefly conducted the affairs for several months during the illness of Assistant Secretary Rathbun, whose death occurred shortly after the close of the fiscal year. It is therefore unnecessary here to do more than to review some of the principal activities of the Museum and to refer to the appendix for further information.

The exhibits are now housed in three buildings: (1) the arts and industries collection in what is known as the old Museum building, (2) the natural history collections and the National Gallery of Art in the large new building, and (3) the graphic arts and National Herbarium in the original Smithsonian building.

During the year 69,286 square feet of room in the Natural History Building were turned over to the Secretary of the Treasury for use of about 3,000 clerks of the War Risk Insurance Bureau. I may mention here that a few weeks after June 30 the building was closed to the public, the exhibition cases were crowded into the least possible quarters, and all available space was temporarily given over to the Insurance Bureau. This course was gladly taken, in order to put into immediate effect the financial assistance provided by Congress for the families of our soldiers and sailors.

About 1,300 accessions to the Museum were recorded during the year, aggregating nearly 143,000 specimens and objects, including 11,000 pertaining to the department of anthropology, 61,500 to zoology, 38,000 to botany, 11,300 to geology and mineralogy, and 17,900 to paleontology; 168 paintings and other art objects were lent for exhibition in the gallery of art.

Among the most interesting additions of anthropological objects were over 400 specimens from Celebes, East Indies, illustrating agriculture and household economy in that region collected through the generosity of Dr. W. L. Abbott. A collection given by Mr. Alfred M. Erskine represented implements and costumes of the Dyaks of Borneo. A noteworthy addition to the division of American archeology was a collection of 83 specimens, mostly stone implements, also relics from the cliff and cavern dwellings of New Mexico, Indian relics from the Virgin Islands, and a large number of relics from Utah. By an exchange with the Royal Ontario Museum of Toronto there were acquired about 200 specimens of Babylonian tablets and prehistoric stone implements from Egypt, France, and England.

The division of mechanical technology was enriched by the addition of a large number of firearms and firearm appliances. Among the historical objects received were two flags pertaining to the present war, one of which belonged to *Zeppelin 49* at the time of its capture in 1917; the other was the flag used at the funeral of the American soldiers lost on the transport *Tuscania* in 1918. A most interesting object is the original letter written by Gen. Grant demanding the unconditional surrender of Fort Donelson. There are also large numbers of souvenirs of American soldiers and statesmen, among which may be mentioned a number of personal relics of Maj. Gen. George B. McClellan, United States Army, consisting of swords, uniforms, and other objects owned by him during the Mexican and Civil Wars; also the well-known Robert Hewitt Collection of Medallie Lincolniana made up of some 1,200 medallions, medals, tokens, and badges. To the collection of musical instruments were added five American pianos and one organ, seven English pianos, two Austrian grand pianos, and a number of other instruments. To the numismatic collection was added a large number of replicas of United States service medals and to the collection of philatelic material, 3,186 stamps, 2,706 of which were received from the Post Office Department. In the appendix the administrative assistant enumerates important additions in the departments of anthropology, biology, geology, and to the arts and industries collections which need not be repeated here.

In previous reports I have called attention to the rapid development since 1912 of the collection of textiles, woods, and medicines. The additions to the collection, showing the methods of making tex-

tiles and finished products, are most instructive, likewise the collection of materia medica, which has been largely increased.

The division of mineral technology during the year has published a number of unusually important pamphlets on the resources of the United States, power, petroleum, nitrogen, and coal. Some interesting objects added to the exhibits in the division include models showing the occurrence and recovery of gold and the manufacture of lead and exhibits of coal-tar products.

The construction of the building for the Freer collection has progressed as rapidly as could be expected under present war conditions. The exterior walls have been erected to entablature height. Nine hundred and twenty-eight items have been added to the Freer collection, including 159 oriental objects. The National Gallery of Art received a bequest comprising 12 paintings, a number of miniatures and other objects, 140 items in all, from the estate of Mrs. Mary Houston Eddy, to be known as the A. R. and M. H. Eddy donation. It has also received from the Russian artist, Ossip Perelma, a portrait by himself of M. Boris Bahkmeteff, first ambassador of the Russian Republic to the United States.

The number of visitors to the Natural History building during the year 1917 aggregated 306,003 on week days and 95,079 on Sundays, and to the Arts and Industries building the number was 161,298. The number of visitors to the old Museum building since it was opened to the public in 1881 has been 8,000,000; to the new building since 1909, 2,643,654; and to the Smithsonian building since 1881, 4,734,492. Many meetings of various scientific societies were held in the Museum auditorium during the year. Special exhibits have also been shown, among the most interesting of which were the collection illustrating the united organizations of the United States Food Administration and the exhibit of etchings of war industries by Pennell.

Following the custom of many years there was a distribution of some 8,000 duplicate specimens to schools and colleges for educational purposes, all properly classified and labeled. These included sets of molusks, ores, minerals, and objects of ethnology and archeology.

The Museum publications of the year comprised 6 volumes and 40 separate papers, including the annual report for 1916, volume 51 of the *Proceedings*, and 5 bulletins. Bulletin 102, on the mineral industries of the United States, is of particular interest to the public, the four parts so far issued being devoted to coal products, fertilizers, sulphur, and coal.

Additions to the Museum library amounted to 3,230 volumes and 1,571 pamphlets, making the present aggregate of 52,534 volumes and 84,491 pamphlets and unbound papers. To the Biltmore collection of botanical works, presented by Mrs. George W. Vanderbilt, 2,000 volumes were added.

BUREAU OF AMERICAN ETHNOLOGY.

The activities of the Bureau of American Ethnology are limited to the study of the past and present conditions of the North American Indians. Their main purpose is to perfect the existing classifications of the various stocks of these aborigines based on their language in order to discover their relationship, and to gain a clearer insight into the origin, history, and migration of man on this continent. The languages of the Indians are doomed to disappear in the near future: some have already gone and others will become extinct in a few years. Through intense, patient research the bureau is undertaking the task of recording these vanishing tongues before they disappear forever.

The bureau is also, through archeological work, resurrecting from the night of the past hitherto unrecorded chapters of the history of aboriginal Indian life that reached a high development and disappeared before recorded history began. One evidence of a prehistoric phase of Indian life is indicated by the pueblos and cliff dwellers. Through erosion by the elements and vandalism due to man these remarkable houses are rapidly falling into decay. The Bureau of Ethnology is cooperating with the Department of the Interior in the excavation and repair of these remains in order that they may be of educational value and preserved for posterity.

The field researches of the bureau the past year have been particularly important, both from ethnological and historical points of view. Hitherto unknown prehistoric monuments have been discovered and surveyed, while others previously known have been excavated and permanently preserved. The advances made in ethnological knowledge, although often slow, are always important and have opened up new problems pleading for solution, indicating that the work of the bureau has barely begun, and that much available information regarding our aborigines still remains to be gathered.

NATIONAL ZOOLOGICAL PARK.

Increasing popular interest in the Zoological Park is manifest by the number of visitors, which aggregated 1,593,337 in 1918 as compared with 564,634 in 1909 and 633,526 in 1913. The park is an educational center as well as a place of resort for recreation and pleasure. This is shown by the fact that 78 schools and classes visited the park in 1918, with a total of 4,945 individuals. It is likewise a center for the life-history study of animals, for they are placed as nearly as practical in conditions of their natural environment, and as the collection increases in numbers or in kinds so does its value become of more importance as a source of scientific information.

There is now in the park a total of 1,247 animals, representing 345 distinct species. These include 483 mammals, 706 birds, and 58 reptiles. The several species are enumerated in detail in the superintendent's report in the appendix.

A most interesting recent accession is the first specimen of the glacier bear or blue bear ever known to have been captured alive. It has a very limited distribution in the region of the St. Elias Alps, near Yakutat Bay, Alaska. Being one of the rarest and least known of the great game animals of America, specimens have been eagerly sought for zoological gardens. Among other accessions may be noted keas, or sheep-killing parrots, and some flightless rails from New Zealand, and a large boa constrictor, 11 feet long, from Trinidad.

For several years I have urged the purchase of certain parcels of land along the western boundary of the park and in 1913 an appropriation was made by Congress for that purpose, but as the purchase could not be completed before the time limit of the appropriation, further legislation becomes necessary for renewal of the allotment.

The superintendent calls attention to a number of important needs, including roads, bridle paths, automobile parking space, grading and filling, a new aviary building, a reptile house, and outdoor quarters for mammals.

A striking mark of the appreciation and interest of the children of Washington in the National Zoological Park is the tablet placed in the elephant house to the memory of the elephant "Dunk," through subscription to a popular fund by the children of Washington, "whose favorite Dunk was for more than a quarter of a century."

ASTROPHYSICAL OBSERVATORY.

The general direction of the work of the Observatory has continued under Dr. C. G. Abbot, who, in addition to these duties, has been occupied during the year with a number of scientific investigations directly connected with the war.

The investigation of the absorption of long-wave rays by long columns of air containing known quantities of water vapor, reference to which was made in my last report, have been continued and the results to date published in the Smithsonian Miscellaneous Collections. In describing his work Mr. Fowle says:

The main purpose of this research was to determine the transparency of water vapor, under atmospheric conditions, to radiation such as the warm earth sends toward space. Upon the absorptive property of water vapor rests in part the virtue of the atmosphere as a conservator of the heat which the earth receives from the sun. Radiation from the sun reaches the earth's surface diminished by a certain portion scattered toward space and certain other portions absorbed in the gases and vapors of the atmosphere. The return of the energy of this radiation back to space is an indirect process. The

warmed earth is cooled partly by convection currents playing over its surface and partly by direct and indirect radiation through the constituents of its atmosphere. Of these the principal hindrances to free radiation are aqueous vapor and carbonic acid gas.

Mr. Fowle's investigations have fixed the dependence of the transmission of the atmosphere on humidity for all wave lengths up to 17 microns. This covers a region of spectrum about fifty times as long as that which is visible to the eye. At about 17 microns rock salt, which is used in preference to glass for optical work on long-wave rays because glass is opaque, itself becomes opaque. Further progress in the important region between 17 and 50 microns depends on finding a new transparent medium. Experiments by Mr. Aldrich have shown that potassium iodide is suitable. But hitherto this substance has yielded no crystals bigger than buckshot. Fortunately, new methods devised for war purposes seem likely to furnish large crystals of this substance and there is great hope that the investigation of atmospheric transparency may soon be carried further.

The total solar eclipse of June 8, 1918, was observed at Lakin, Kans., by Mr. Aldrich, of the Observatory, with two assistants. Some good photographs of the solar corona and other phenomena were secured. Throughout the afternoon and early night hours of June 8 and 9 observations were made with the pyranometer. The results "measure the gradual diminution of the radiation of the sun and of the brightness of the sky as the eclipse progressed, the outgoing radiation of the earth's surface during totality, the gradual increase of sun and sky radiation afterwards, their decline toward sunset, and the outgoing radiation from the earth's surface after nightfall."

Investigations at Mount Wilson of the variability of the sun have been continued and improved. Observations were also made at Hump Mountain, N. C., but that station was abandoned as too cloudy, and in June, 1918, a station believed to be exceptionally well located was established near Calama in Chile at an altitude of 2,250 meters where meteorological records indicate 300 days per year favorable for solar constant work. This station is supported by a grant from the Hodgkins fund. It is in charge of Mr. A. F. Moore and is exceptionally well equipped.

INTERNATIONAL EXCHANGES.

The total number of packages handled by the International Exchange Service during the year was 266,946, weighing 182,825 pounds, as compared with 399,695 pounds in 1917, the decrease being due almost entirely to war conditions.

The operations of the exchange service have been somewhat curtailed during the past year by the impossibility at times of obtaining

cargo space. This condition and the excessively high freight rates necessitated shipments by mail where this could be done advantageously. Notwithstanding the scarcity of shipping, it is significant that governmental licensing boards for imports and exports, both of this country and of Great Britain, have recognized the importance of keeping open the interchange of scientific information by granting licenses to the Institution and its agents for the transmission of this material. Only three consignments of exchanges have been lost through hostile action since the beginning of the war.

In the interchange of Government publications 91 sets of United States governmental documents were received for distribution to designated depositories in foreign countries.

INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE.

The United States Bureau of the International Catalogue of Scientific Literature is carried on by the Smithsonian Institution by means of a congressional appropriation. The central bureau is in London, where data from regional bureaus are assembled and published in series of annual catalogues. The war has very greatly interfered with this work, some countries being so much in arrears in their contributions toward its support as to necessitate unusually large subscriptions from several institutions.

As its name indicates, the catalogue is made up of bibliographical references to scientific literature in various countries. The United States bureau since 1910 has collected data for this country, aggregating more than 350,000 reference cards. The 17 annual volumes issued in London are sold at an annual subscription price of \$85, chiefly to large reference libraries and important scientific institutions, the proceeds covering in part the cost of the publication.

At the international convention in London in 1910 a committee was authorized to secure cooperation with other similar organizations in the preparation of the catalogue and to broaden its scope to include technical industries closely allied to researches in pure science. This would not only lead to economy of labor but would provide a uniform reference to the literature of all sciences.

NECROLOGY.

WILLIAM JOEL STONE.

William Joel Stone, A. B., LL. D., United States Senator, regent of the Smithsonian Institution, was born in Madison County, Ky., May 7, 1848, and died April 14, 1918. Mr. Stone was educated at Missouri University, which later conferred upon him the degree of

LL. D. He was admitted to the bar in 1869, after which he was successively prosecuting attorney of Vernon County, Mo., Representative in the Forty-ninth, Fiftieth, and Fifty-first Congresses, and governor of Missouri. He was a member of the Democratic National Committee from 1896 to 1904, vice chairman of the committee from 1900 to 1904, and in 1903 was elected to the United States Senate, to which office he was twice reelected. He was regent of the Smithsonian Institution from 1913 until his death.

CHARLES WARREN FAIRBANKS.

Charles Warren Fairbanks, A. B., A. M., LL. D., twenty-sixth Vice President of the United States, regent of the Smithsonian Institution, was born in Union County, Ohio, May 11, 1852; died June 4, 1918. Mr. Fairbanks was educated at Ohio Wesleyan University, was admitted to the Ohio bar in 1874, and established practice at Indianapolis, Ind. He was delegate and chairman in several national political conventions, United States Senator from Indiana from 1897 to 1905, Vice President of the United States from 1905 to 1909. During his term as Vice President he was ex officio regent of the Smithsonian Institution, and was again regent by resolution of Congress from 1912 until his death.

Respectfully submitted.

CHARLES D. WALCOTT, *Secretary*.

APPENDIX 1.

REPORT ON THE UNITED STATES NATIONAL MUSEUM.

SIR: Owing to the death on July 16, 1918, of Mr. Richard Rathbun, Assistant Secretary of the Smithsonian Institution in charge of the National Museum, the duty devolves on me of submitting the following report on the operations of the United States National Museum for the fiscal year ending June 30, 1918:

WAR ACTIVITIES.

During the trying conditions that have prevailed in the United States since it entered the war, the National Museum has demonstrated its value as a national asset in many ways. Members of its staff of experts, its great collections, its laboratories, and all the information in its possession, have been placed unreservedly at the service of the executive departments and other Government agencies, and have been freely used by a number of them. Some of its exhibition halls have been closed to visitors and turned into office quarters for one of the important war bureaus of the Government. Facilities for the comfort and recreation of officers and men stationed in the vicinity and drilling on the Mall have been provided in the buildings, and the reading rooms of the libraries have been equipped with tables and writing materials for all men in uniform.

Its department of geology has been frequently called upon to furnish the Bureau of Standards, Naval Experiment Station, Department of Agriculture, Geological Survey, the Carnegie Institution, and various arsenals, materials for experimental work. A single call from the Bureau of Standards embraced 27 varieties of minerals, many of which were rare. To meet all of these demands, it has been necessary to make trips into the field to secure additional supplies. At the request of the National Research Council the head curator of this department has taken over the entire work of securing optical quartz for the needs of the United States and of Great Britain, involving a large volume of correspondence and travel to different points.

The division of mineral technology has concentrated its activities for the year upon the interrelationships, and consequent interdependence, existing in the industries sustained by mineral resources. In addition to instructive exhibits, the curator and his assistants, in the solution of the problems connected with the fertilizer, sulphur, fuel, and power situations, have prepared for publication pamphlets which

have been not only in great demand by publishers of technical papers, engineers, and business enterprises interested, but of particular value to the Government bureaus handling these matters. They have furnished, also, a large amount of data to the Shipping Board, the fuel and fertilizer administrations, and the War and Navy Departments, including suggestions for insuring a sustained source of oil, and for the systematic assemblage of industrial data as a basis for reconstructional work in man power.

The division of physical anthropology has furnished a large amount of information on racial questions, particularly relating to the Balkans, to the National Research Council, and the Army and Navy Intelligence Bureaus.

In the conservation of food, the curator of the division of textiles, having charge of food and animal products, cooperated with the Food Administration in planning graphic exhibits for use throughout the country on the subject of conservation. He was also appointed exhibits director in the District of Columbia and served as chairman of the campaign committee to carry out food conservation in the District. Incidentally he has prepared and placed on exhibition an instructive exhibit of foods in the National Museum. Information was also furnished by him to the United States Shipping Board on raw commodities, and assistance in working out a system for classifying commercial data on vegetable fats and oils.

The Museum photographer has rendered valuable assistance in connection with the organization of laboratories in the War and Navy Departments, and also in confidential matters.

Other lines of work in which the Museum was active included geological and biological problems arising in gas warfare, peat investigations, questions in connection with the construction of concrete ships and other similar problems, the translating of communications, etc.

Since the war commenced 24 employees of the Museum have been granted furloughs to enter the military service of the country.

Bureau of War Risk Insurance.—In October, 1917, at the request of the President of the United States, space in the natural history building of the Museum was placed at the disposal of the newly organized Bureau of War Risk Insurance of the Treasury Department, the foyer on the ground floor and the adjoining rooms being converted into offices for the preliminary stages of the work. By rearranging some exhibition halls and by closing others, additional space was given for the purpose from time to time as the force of the bureau increased, so that at the close of the fiscal year the bureau occupied 69,286 square feet in the foyer, adjoining rooms, auditorium, and ranges on the ground floor, and in the rotunda and the exhibition halls on the first floor, extending from the center of the north

hall around east through the southern section of the west hall, providing accommodations for 3,059 employees. This occupancy necessarily involved many changes and inconveniences, including the closing of the auditorium, with the cancellation of meetings and congresses. The importance of the work with which the bureau is charged—not only of providing insurance for the soldier and sailor, but of paying to their dependent families the allotments made by them and by the Government—more than justified any and all sacrifices required, and the heartiest cooperation and assistance was cheerfully rendered by the entire staff of the Museum.

On July 16, 1918, at the further request of the President, the Board of Regents closed the natural history building to the public, in order to make every foot of space in the exhibition halls available for the Bureau of War Risk Insurance.

COLLECTIONS.

The additions to the collections, received in 1,288 accessions, aggregated approximately 142,902 specimens and articles, classified by subjects as follows: Anthropology, 11,058; zoology, 61,537; botany, 38,123; geology and mineralogy, 11,370; paleontology, 17,896; textiles, woods, medicines, and other miscellaneous animal and vegetable products, 1,532; mineral technology, 308; and National Gallery of Art, 1,078. Seven hundred and eighty-one lots of material were received from various parts of the country for examination and report.

Space here permits the mention only of some of the important additions of the year.

Anthropology.—The ethnological collections were increased by some 400 specimens collected in Celebes by Mr. H. C. Raven and presented by Dr. W. L. Abbott; examples of the work of the Dyaks of Borneo, donated by Mr. Alfred M. Erskine; African, Chinese, Filipino, and Porto Rican ethnologica from Miss Josephine A. Rohrer; baskets from the Koasati Indians, a pottery-making series of the Catawba Indians, Sioux and Chippewa objects, and Voodoo drums and charms from Haiti.

Through explorations under the Smithsonian Institution came relics from ancient cliff and cavern dwellings in New Mexico collected by Dr. Walter Hough, and archeological objects from Utah gathered by Mr. Neil M. Judd. The Museum of the American Indian, Heye Foundation, sent an exchange of ancient Indian relics from the Virgin Islands, including stone implements and pottery. Stone implements were also received from Mr. J. G. Braecklein, and prehistoric implements gathered in Mexico from the Bureau of American Ethnology. Effigy earthen vessels from the Casas Grandes, Mexico, were donated by Miss Edith Symington, and an-

tique pottery with glaze color designs from Arizona by Mr. Victor J. Evans. The Royal Ontario Museum of Archeology, Toronto, contributed, by exchange, important Old World archeological objects, including Babylonian inscribed cuneiform tablets, stone implements from Egypt, France, and England, bronze and iron implements from Greece and Italy, besides Egyptian pottery, beads, coptic cloth, and arrowheads. A unique roasting spit found near the Colosseum, a marble head of Hercules, and some Roman coins were among the objects donated by Capt. Clarence Wiener of the British Army; of particular interest also were a bronze lamp, a rosary of Kentucky coffee beans, and a prayer book and selections from the Scriptures arranged for Jews serving in the Army and Navy of the United States.

The division of physical anthropology was enriched by Indian skulls and other bones from Alaska, Florida, Illinois, and the Navaho Reservation, a skull from the French Congo, an interesting cranium from the Malay Archipelago, a skull and part of the skeleton of an Eskimo, various other skeletal specimens, and plastic restorations of certain supposedly early man.

The original full-sized Langley flying machine of 1903 and a duplicate set of cylinders for the engine were deposited in the Museum by the Institution. Begun by former Secretary S. P. Langley for the War Department in 1898, in the interest of national defense, this machine has been demonstrated to be the first aeroplane constructed capable of sustained free flight carrying a man.

To the mechanical collections were added also revolvers and swords of Santo Domingo manufacture; modern firearms of English and American make, including a British Enfield rifle, model of 1914, and an up-to-date high-power sporting rifle; three guns which belonged to the late William Cost Johnson, Member of Congress from Maryland, 1833-1843; primitive appliances used with sporting rifles from 1840 to 1870; a crude iron box with flintlock attachment designed for firing an explosive; molds for casting lead bullets; a signal pistol used by the United States Navy in 1884; and a blunderbuss said to have been used in defending mail coaches running between Baltimore and Washington in the olden time.

Mr. Hugo Worch added 26 pieces to his previous munificent donation illustrating the history and development of the pianoforte, and including dulcimers, spinets, clavichords, harpsichords, and organs, increasing the extent of this notable collection to 143 instruments.

The J. Lewis Ellis and Olive M. Ellis Memorial Collection was increased by an extensive series of articles in glass, porcelain, silver, and embroidered handkerchiefs and other textiles. Examples of Venetian glass, showing miniature portraits and landscapes by the famous glassworker, Jacopo Franchini, were received from Cavaliere

Salvatore Arbib through the American consul at Venice, Mr. B. Harvey Carroll, jr. Two bronze vases presented by the Government of Japan in 1884 to Commander John B. Bernadou, United States Navy, reached the Museum through bequest of his widow. Among loans were period china and Dresden groups and Japanese and Chinese ivory carvings.

To the division of graphic arts came woodcut blocks and progressive proofs from them, the work of Gustave Baumann; specimens of intaglio color printing from Miss Gabrielle De V. Clements; illustrations of the new process "brulegravure," from the inventor, Mr. John Williams Robbins, and an akrograph portrait made by Lord Kelvin.

The historical relics included a flag flying on the Zeppelin *L-49* at the time of its capture at Bourbonne les Bains, France, October 17, 1917, by Lieut. Lefevre, of the French Army, which reached the Museum by transfer from the United States Marine Corps, through Maj. Gen. George Barnett, commandant. This was accompanied by small fragments of the gas bag and of the outer envelope of the *L-49*. Another trophy, received through President Wilson, was the American flag made at Islay House, Islay, Scotland, for use at the funerals of American soldiers lost with the transport *Tuscania*, February 5, 1918.

The original note written by Gen. U. S. Grant to Lieut. Gen. Simon B. Buckner, Confederate States Army, demanding the unconditional surrender of Fort Donelson, was contributed by Mrs. Glenn Ford McKinney, and a large collection of relics pertaining to Maj. Gen. George B. McClellan, United States Army, including a number of swords, came as a gift from his son, Hon. George B. McClellan.

Among other historical relics received were a gold watch owned by Maj. Gen. C. C. Washburn; uniform chapeaux, epaulets, military insignia, and uniform buttons worn by Col. John N. Macomb, United States Army; a uniform coat of Gen. Samuel Jones, Confederate States Army; a fragment of the Confederate military balloon made in Richmond, Va., of silk dresses; relics of the War of 1812-1815, the War with Mexico, and the Civil War, brought together by Bvt. Maj. Gen. Edward D. Townsend, United States Army; a sword carried by Col. William Dudley during the War of 1812-1815; and a snuffbox given by Rear Admiral Charles Stewart, United States Navy, to Coxswain William C. Parsons, who in turn presented it to Rear Admiral George H. Preble, United States Navy. The naval service was further represented by relics relating to Admiral David G. Farragut, from the estate of his son Loyall Farragut, augmenting the large collection received a year ago. A sword and pair of flintlock pistols owned by Brig. Gen. Daniel Roberdeau

during the Revolution, and a spyglass and steel tape measure used by Lieut. Col. Isaac Roberdeau, when assisting in laying out the city of Washington, were among objects lent to the Museum, as was also a portion of the set of chinaware presented by Gen. Lafayette to Mr. and Mrs. George Graham, of Virginia.

To the historical costumes were added knee breeches and waistcoat worn during the Revolution by Col. Tench Tilghman; the official costume and sword of William L. Dayton, American minister to France in 1861-1864; the official costume and sword of William L. Dayton, jr., secretary to the American Legation in Paris during that period; and a satin dress worn by Mrs. Annette Henry Alger, wife of Russell A. Alger, Secretary of War, 1897-1899.

Particularly noteworthy is the collection of medallic Lincolniana assembled through many years by Mr. Robert Hewitt, of New York City, and presented by Mrs. Hewitt, consisting of 1,200 medallic souvenirs, including medallions, plaques, medals, coins, tokens, and badges. The Robert Hewitt collection is remarkable for the very wide range of subjects and types of numismatic material which it covers, and constitutes an epitomized medallic record of the career of President Lincoln. The United States Mint contributed a large series of bronze replicas of United States military and naval service medals, commemorative medals, and medals of award.

The philatelic material in the Museum was augmented by 3,186 specimens. Of the 2,706 transferred from the Post Office Department, 1,506 represented new issues received by the Department from the International Bureau of the Universal Postal Union.

Biology.—While the various divisions of this department report a decrease both quantitatively and qualitatively in the additions of the year, it is notable that they relate in most instances to the floras and faunas of foreign lands remote from the scene of war and war preparations.

Another trip to Haiti by the indefatigable collector and generous friend of the Museum, Dr. W. L. Abbott, resulted in important material for the Museum from that and adjoining islands, including new and rare forms of birds and reptiles. Mr. H. C. Raven, operating under the auspices of Dr. Abbott, continued collecting birds and mammals in Celebes, moving toward the middle of the island and visiting one or more of the high peaks. He obtained interesting species and genera not found at lower levels, some of the species apparently new to science and several genera new to the Museum collection. Coming from the border country between north and south Celebes, the faunas of which differ considerably, the full significance of the series can only be appreciated when the entire Celebes collection has been carefully studied.

The Bureau of Science at Manila contributed a large lot of plants from Amboina, Borneo, and the Philippines. From the Philippines came also an important collection of named chaetognaths transferred by the Bureau of Fisheries, and land shells donated by Mr. Walter F. Webb; and butterflies from the Philippines and Yucatan were contributed by Mr. B. Preston Clark. Hawaii sent a large lot of plants collected by Mr. A. S. Hitchcock, besides algae and mollusks.

South America was represented by the important collections of mammals, amphibians, and reptiles collected by the Peruvian expedition of 1914-15, under the auspices of Yale University and the National Geographic Society, adding the first fully representative series in these groups received by the Museum from any large area of South America. The Museum has been and is even now extremely deficient in material from that continent, and the collections presented by the authorities responsible for this expedition are therefore of the utmost value as forming the basis of future work by American zoologists in that long-neglected field. A collection of fishes from western Colombia, received by exchange from the Carnegie Museum, Pittsburgh, supplements material obtained a few years ago in connection with the Smithsonian biological survey of the Isthmus of Panama, as did also a series of plants from Panama contributed by Mr. Ellsworth P. Killip. From Argentina, Venezuela, Curaçao, and the Galapagos Islands came large lots of plants.

South and Central America, as well as western United States, were represented in the donation by Dr. Harrison G. Dyar, custodian of Lepidoptera, of personal collections aggregating some 35,000 insects and including some 15,000 named Lepidoptera, 1,000 named sawflies, and large series of mosquitoes and miscellaneous Diptera.

A new genus and species of river dolphin from Tung Ting Lake, China, afforded a remarkable novelty in the increment to the mammal collection, belonging to a group of porpoises which includes numerous extinct forms found fossil in Europe and the eastern United States, its only known living relative occurring in the large rivers of South America.

In northern China interesting series of birds, mammals, fishes, reptiles, and insects were collected for the Museum by Mr. Arthur de C. Sowerby, who has lately returned to England for war duty. These supplement collections made by him in that country for the Museum during the past 10 years. From China came also some 1,200 plants from the Canton Christian College, and Chinese and Japanese plants were obtained from the Arnold Arboretum of Harvard University.

The Collins-Garner Congo expedition, on which the Museum is represented by Mr. C. R. W. Aschemeier, sent large lots of well-prepared mammals and birds and smaller numbers of insects, plants, and shells from the French Congo, greatly needed for comparison with the

remarkable East African series in the Museum. Of birds alone this contains 10 or more species hitherto not possessed by the Museum and at least 1 genus.

The Public Library Museum and Art Gallery of Western Australia, at Perth, supplied in exchange a number of particularly desirable mammals, birds, reptiles, and batrachians from Australia.

Even the Arctic contributed to the additions of the year. Nearly 700 crustaceans and mollusks collected by the Canadian Stefansson Expedition to the Arctic, 1913-1916, were presented by the Dominion Commission of Fisheries, Department of Naval Service, Ottawa, in recognition of services rendered by members of the Museum staff in identifying material.

During his explorations in British Columbia, Secretary Walcott collected for the Museum a number of large mammals, including a family of moose, which form a valuable addition to the North American series of mammals. The activities of various Government agencies, mainly the Bureau of Fisheries and the several bureaus of the Department of Agriculture, resulted in much material for the Museum from the United States, representing practically every branch of biology and including particularly large series of grasses and insects. Of North American material mention should also be made of especially well prepared bird skins and skeletons from southern California presented by Mr. Edward J. Brown; marine invertebrates collected in Magdalena Bay by the donor, Mr. C. R. Orcutt; a killer whale from Florida representing a genus new to the coasts of the United States contributed by Mr. Lawrence S. Chubb, and plants from Alaska and California from Prof. W. L. Jepson.

Various localities, both domestic and foreign, were represented in an exchange from the Boston Society of Natural History of over 2,300 crustaceans and mollusks, and some 12,000 specimens of American and foreign bird eggs were lent to the Museum by Dr. T. W. Richards, U. S. Navy.

Geology.—Special attention was paid to building up the collection of minerals heretofore classed as rare earths and rare metals, which have become of importance through the outbreak of the war. A group of exhibition specimens secured mainly through the efforts of Mr. F. L. Hess consists of a large mass of scheelite ore weighing 2,614 pounds, showing the full width of the vein and said to be the largest mass of tungsten ore yet mined; about 100 pounds of molybdenum-copper ore showing the interesting geological associations of molybdenite; partly oxidized tungsten showing the atmospheric alteration of the common tungsten ore mineral wolframite; scheelite ore replacing limestone and showing unusually large cleavage surfaces of the ore mineral; a sawn mass of brecciated ferberite ore—the so-called “peanut ore;” a specimen of molybdenite; molybdenite

and molybdenite in altered rhyolite; a mass of the newly discovered sulphide tungstenite; crystallized ferberite; and a collection of 15 ores and minerals, including molybdenite from Canada, carnotite replacing wood, ferberite in the form of iridescent crystals, and a specimen of the rare uranium-vanadium mineral uranite impregnating friable sandstone.

The exhibit of steel-hardening metals was further augmented by specimens of vanadium ores with incrustations of crystals of the ore minerals vanadinite and descloizite. Other gifts of interest include a series of specimens from the famous nitrate deposits of Chile showing the caliche and its natural associations, a cross-fiber vein of asbestos showing unusually long pure fibers, and sandstone impregnated with the blue molybdenum sulphate, islemanite.

Collections made for the division by members of the staff included large exhibition specimens illustrating unconformities, conglomerates, rock phosphate, and phosphatic limestone secured by Dr. R. S. Bassler; albite crystals of unusual type, columbite, black mica, staurolite, bauxite, and quartz, the last named mainly for use by the Signal Corps of the Army, collected by Dr. George P. Merrill; rocks to illustrate weathering, obtained by Dr. J. C. Martin; sphalerite with associated minerals and brecciated chert, and apatite and hematite, collected by Dr. Edgar T. Wherry.

A mass of graphite, showing an unusual columnar structure, was transferred from the United States Geological Survey, as were also blocks, fragments, and pebbles from an Alaskan glacial ground moraine of Silurian age, and a choice figured specimen of arborescent calcareous sinter from the Mammoth Hot Springs, Yellowstone National Park.

Of meteorites there were added a newly found stone from Eustis, Fla.; a slice of the Carleton siderite; 280 grams of an undescribed stone from Kansas City, Mo.; and an 826-gram specimen of the Burkett (Tex.) meteoric iron.

In the division of mineralogy and petrology gifts of exceptional value from Mr. C. S. Bement included particularly fine exhibition specimens of hetaerolite, crystals of rhodonite, zincite, leucophoenicite, manganosite crystals, a cut gem, a free crystal and an embedded crystal of willemite, and willemite with friedelite and white zeolite, all from Franklin, N. J.; calamine, pyrite, and milky quartz, from Colorado; free crystals of scheelite and scheelite crystals attached to chalcopyrite, from Mexico; an exceptionally fine, large twinned crystal of quartz and an unusual crystal of danburite, from Japan; the rare mineral achtaragditite and a variety of vesuvianite—wiluite—from Siberia.

The American consul at Changsha, China, Mr. Nelson T. Johnson, donated a specimen of twinned cinnabar crystals from China, show-

ing seven groups of crystals more than half an inch in diameter, and as far as known the finest of its kind in the United States.

Other additions included crystals of tetrahedrite embedded in quartz, galena with crystals of anglesite, gem stones of variscite, opalized shells from the Cretaceous of South Australia, beryl, milky quartz crystals, crystals of selenite, large pyrites, aragonite crystals, besides type specimens presented by Dr. Henry S. Washington, of the Geophysical Laboratory, and minerals described by Prof. A. S. Eakle, of the University of California, and by Dr. W. F. Hillebrand, of the Bureau of Standards.

Specimens illustrating the geology and ore deposits of the Tintic district, Utah, the basis of Professional Paper 107, of the Geological Survey, by Prof. Waldemar Lindgren and Dr. G. F. Loughlin, were received as a transfer from the Survey, and an interesting series of rocks collected in the Orient by Dr. J. P. Iddings, in 1910. was formally turned over to the Museum.

Of the increment to the collections of invertebrate paleontology mention should first be made of about 10,000 specimens of Middle Cambrian fossils obtained by Secretary Walcott from the celebrated locality at Burgess Pass, British Columbia, comprising the study and reserve material of this wonderful fauna, the types of which were previously received as were these, by deposit from the Smithsonian Institution.

A number of large fossils, mainly corals, and fossiliferous limestone slabs were collected by Dr. Bassler for enlarging the coral reef installed in the exhibition series last year.

Well preserved invertebrate fossils from the Cretaceous formation of Tennessee constituted the most important addition to the Mesozoic collections. Of interest both for exhibition and study were fossil insects preserved in copal resin, collected by Prof. D. S. Martin by searching the gum copal from the Pleistocene deposits of East Africa shipped in large quantities to the varnish factories in the vicinity of Brooklyn.

Paleozoic and Mesozoic fossils especially selected to round out the study series of European forms, and ammonites from the Jurassic rocks of France needed in the revision of the exhibit of these forms, were secured by exchange. To the study series were added Tertiary fossils from the Pacific coast, and the Devonian stratigraphic series was increased by a rather complete representation of fossils from the Hackberry and Hamilton groups of Iowa. Small lots of well-preserved Eocene insects and a fossil fish collected in Colorado were of interest because of their rarity.

The section of vertebrate paleontology secured from the United States Geological Survey, the most important collection of fossil turtle remains ever brought together from the southwestern part of

the United States, many specimens being suitable for exhibition and no less than 49 are sufficiently well preserved to be identified specifically. Other well-preserved turtles acquired included the type of a box turtle described by Dr. O. P. Hay, and an example from the Cretaceous of Georgia, valuable chiefly on account of its locality.

Fossil bones of the mammoth, rhinoceros, and horse collected for the Museum in Siberia by Mr. John Koren to supplement the material obtained by the Koren expedition in 1914-15, included a beautifully perfect mammoth humerus over 3 feet in length, indicating an animal of magnificent proportions.

Type material comprised the important additions in paleobotany. Fossil plants from Wyoming, the basis of a paper by Dr. F. H. Knowlton, were transferred from the survey; two lots from South America were contributed by Prof. E. W. Berry, the first from the Tertiary rocks of Bolivia, valuable not only as type specimens, but in furnishing data for additions to the geologic history of that country, the second from the Miocene of Peru; and specimens from Beaver County, Okla., described by Prof. Berry, were donated at his request by Prof. E. C. Case.

Textiles.—The efforts of domestic manufacturers to take advantage of the opportunity afforded by the war is shown by upholstery velvets and velours manufactured in this country from mercerized cotton, mohair, or silk, or combinations of these, including antique venetians made of mercerized cotton in imitation of old French and Italian fabrics and intended to take their place at a reasonable price.

The silk goods series was augmented by new figured novelty silk representing beautiful effects in the cross-dyeing of combinations of cotton, wool, artificial silk and spun silk, brocade piece-dyed satins, figured cross-dyed crêpe georgette, crêpe metcore, and fabrics printed in designs suggesting water movements, silk poplins, georgette crêpe printed in spiderweb-like design called "camouflage," and suggesting Japanese batik work, "Moon-Glo" crêpe, a novelty crêpe weave fabric with metalliclike surface, and a rough surface fabric printed with an all-over oriental design.

Fine silk fabrics ornamented with attractive designs by means of discharge printing are believed to be among the best examples of this method of printing fabrics that have been produced in the United States. These included Luxor taffeta, in Persian, Saracenic, and Italian designs of the eighth, thirteenth, and fourteenth centuries, copies from ancient Peruvian fabrics, and Wedgwood prints which carry out remarkably the relief effect copied from Wedgwood pottery.

Woolen fabrics of the worsted type, woven from combed wools, are well represented in the Museum collections, but the carded woolen industry has not been adequately covered heretofore. Particularly

welcome therefore were some excellent examples of this type of fabric, comprising broadcloth, beaver, zibeline, chinchilla, flannels, overcoatings, and a strong corkscrew-weave fabric used for shoe tops. Owing to the need of conserving wool for use in the manufacture of military clothing, new types of fabrics for civilian use have been put on the market by manufacturers. One of these reaching the museum, "Honey cloth," is a cotton warp worsted having the weft threads composed of one-fourth mohair and three-fourths wool.

To the series of implements used in preparing and weaving textile fibers were added an old flax breaker and two small looms of the types employed in producing Gobelin and Beauvais tapestries, together with a repairing board used in mending such fabrics. Some of the first embroidery machines brought to the United States from Europe are doing war work by embroidering service insignia for the Government. A contribution of 107 specimens of such official emblems of the United States Army, the United States Navy, the Food Administration, and the Boy Scouts of America, on standard uniform fabrics, makes a popular exhibit.

In emphasizing the importance of food conservation a large series of foodstuffs received as gifts from manufacturers or as transfers or loans of Government property enlarged the old section of foods and permitted an exhibit along the line of the Food Administration. Besides series of wheat substitutes, examples of the conservation of surplus fruits and vegetables by dehydrating and by canning were secured, and material to show the high food value of soy beans and peanuts. An exhibit of 74 models of ordinary articles of diet, each one representing a quantity of food sufficient to produce a heat value of 100 calories, shows graphically the relative heat value of the various articles in a manner easily comprehended by everyone.

Hand samples of woods produced by 344 trees indigenous to North America, carefully determined in the preparation of the Tenth Census Report as to value as fuel and for construction, reached the Museum from the United States Naval Academy at Annapolis, and the New York State College of Forestry contributed a collection of wood specimens representing the more important species in use in the industries of New York State. Other additions to the section of wood technology included log sections cut from trees felled in Smithsonian and Seaton Parks in recently clearing the ground for the erection of temporary buildings for the War Department; an elaborate display of "Korelock" doors; a standard aeroplane propeller and an impeller also of laminated wood construction; specimens showing steps in the manufacture of a baseball bat, of a wagon wheel, of an automobile wheel, of a saw handle, of a billiard cue; and various specimens of California redwood.

In the division of medicine efforts were concentrated on obtaining exhibition material of educational rather than scientific value. Illustrating organotherapy was a series of fresh specimens of glands and glandular tissues together with finished products of the different forms in which they are administered. Specimens illustrating the manufacture of pepsin and the finished product in various forms included a sample of pure pepsin with a standardized strength of 1:20,000, that is, it has the power to dissolve 20,000 times its own weight of freshly coagulated and disintegrated egg albumen. Other exhibits of crude vegetable drugs, synthetic medicinal chemicals, inorganic chemicals, plant constituents, opium and its products, cinchona bark, aloes, and cascara sagrada were secured.

Mineral technology.—In assembling collections representative of mineral technology, comprehensive popular exhibits had been arranged at the beginning of the year, comprising abrasives, asbestos, asphalt, cements, coal, copper, glass, gold, graphite, iron, lead, lime, mica, petroleum, plaster, salt, sulphur, and tin. Under existing conditions it was decided to confine activity to enhancement of what was already established, deferring for the time being the various projects for numerical expansion. Accordingly an exhibit was added to the coal series showing the scope of recent American enterprise in the direction of coal product manufacture. It consists of a 200-pound lump of bituminous coal with derivatives in the form of dye-stuffs and other chemicals to the number of 233. The series treating of gold was enriched by a large panoramic model showing the occurrence and the various methods employed in winning the metal. The magnificent panoramic model of the Bingham Canyon Copper Mining operations was completed, as was also the model, in part placed on display a year ago, showing the operations of lead manufacture.

In an effort to be of service in the present emergency of war five lines of investigation, which have been under consideration for several years in assembling exhibits, have been developed in the course of the year. These comprised fertilizer materials, sulphur, coal products, power, and petroleum. To mobilize the economic forces of production and to fill in their gaps is as necessary as that of effecting the requisite military organization, and far more intricate. The difficulty in building up deficiencies as they become apparent lies in the complexity of interrelationship. Especially is this true among the chemically conducted industries. First, there is the group relationship of progressive segregation, notably instanced in the coal-product series, wherein the isolation of any one product entails the work leading to the isolation of many others. Then comes the group relationship of recombination into usable form, as in the case of fertilizer manufacture, where an entirely different basis of inter-

dependence is established drawing variously upon the other groups and linking them together. Thus to build up a deficiency in any one specific direction it often becomes necessary to carry the work of reconstruction far afield.

As applied to mineral derivatives, the question of interrelationship has been a subject of special study in the division of mineral technology from the time of its establishment, and it was felt from the outset that here lay the chief opportunity to render service. When the country's deficiency in fixed nitrogen came up for consideration some two years ago occasion was taken to point out¹ that a nitrogen situation as a thing apart and to itself did not and could not exist—that it was inextricably involved with the coal-product situation and fertilizer situation, and that the only remedy lay in giving heed to this interrelationship. So it is with the work of mobilizing the various other chemically conducted industries on a war-time basis. The need of giving advance heed to this question was appreciated by our enemies—Germany entered the war as fully prepared in this field as in the military branches. It was inadequately appreciated by those who eventually came to be our allies, however; while in the United States, up to the actual outbreak of hostilities, it was entirely disregarded as a national issue. Paramount among the problems thus entailed are those presented by the industrial groups having to do with the fertilizer materials necessary to an adequacy of foodstuffs, and with the energy resources requisite to the work of manufacture. In contributing to the solution of these two basic problems, investigations projected by Mr. Chester G. Gilbert, comprising fertilizer materials, sulphur, coal products, power, and petroleum, have resulted in the publication of pamphlets on the interpretation of the fertilizer situation, industrial independence in sulphur, an object lesson in the resource administration in coal products, and the coal resource and its full utilization. Papers on power and petroleum were completed but not published at the end of the year. In view of the tendency toward duplication in the scientific work in Government departments, it is of special note that it is not purposed to initiate any new scientific or technical lines of work, but merely to interpret technical facts in popular form. This is not only of vital importance but it is peculiarly the function of the National Museum.

NATIONAL GALLERY OF ART.

In the last report it was stated that foundations had been laid for a granite structure on the Smithsonian Reservation to house the Charles L. Freer Collection. Though some delays were encountered

¹ Sources of nitrogen compounds in the United States, by Chester G. Gilbert, Smithsonian Institution Special Publication No. 2421, June, 1916.

in procuring materials and labor, the construction of this building has progressed during the year as rapidly as could be expected, considering the vast undertakings of the Government in constructional enterprises in Washington due to the war. By June 30, 1918, all of the exterior walls were erected to entablature height and about half of the architrave and frieze courses of the entablature were set. Four-fifths of the interior walls had risen to gallery ceiling height and all others were well advanced. The marble walls of the court were completed to about two-thirds of their ultimate height. The basement and first floor construction were completed, the drainage system below the subbasement floor finished, and 10 per cent of the heating and ventilating duct work in the subbasement installed.

During the year Mr. Freer increased the extent of his collection to over 6,200 items by 928 additions, of which 20 are paintings by the American artists Whistler, Tryon, Dewing, Melchers, Metcalf, Sargent, and Brush; while the oriental objects, numbering 908, consist of paintings, pottery, fabrics, jewelry, and objects of jade, bronze, wood, stone, glass, and lacquer.

By bequest of Mrs. Mary Houston Eddy, of Washington, the gallery received a collection of 12 paintings, 12 miniatures, 9 ivory carvings, a Limoges enamel, a marble bust, a bronze statue, and miscellaneous art objects, 110 items in all, to be known as the "A. R. and M. H. Eddy Donation." Other permanent acquisitions were portraits by Ossip Perelma of M. Boris Bakhmeteff, first ambassador to the United States from the Russian Republic, and of Mr. Frank B. Noyes, president of the Associated Press and editor of the Washington Star; a portrait of Vinnie Ream (Hoxie), by G. P. A. Healy; a marble statue of Puck, by Harriet Hosmer; two miniatures by Isabeau, one of Napoleon I, the other of Marie Louise; two old English silver snuff boxes and two large plaster landscape models made in 1902 of the park system proposed for the city of Washington by the commission appointed by the Senate Committee on the District of Columbia.

The special loan exhibitions consisted of a collection of Joseph Pennell's lithographs of war work in Great Britain and the United States, displayed from November 1 to 24, 1917, with a special view on the evening of the 1st; and a series of architectural drawings by Charles Mason Remey, being preliminary designs showing varying treatments in different styles of architecture of the proposed Bahai Temple for Chicago, exhibited during March, 1918.

As elsewhere stated, the natural history building is, under normal conditions, greatly overcrowded with the collections of its departments of biology, geology, and anthropology and of the art gallery, nearly one-fourth of its space being given over to art in its various

forms. The need of considering the erection of a building exclusively for the National Gallery of Art is pressing and should early receive attention. The gallery has already failed to acquire many rich gifts of art works because of the impossibility of caring for them in the present buildings, and other cities are being enriched at its expense. Because of this unpreparedness, treasures of art of great worth well within its reach have gone elsewhere. Art works more than any other national possession typify advanced civilization, and the public demands means of acquiring and keeping and facilities for utilizing such. Most modern nations have made their capital cities principal centers of art development and art accumulation, and progress in this respect may well be regarded as an index of the degree of advancement of the people.

MEETINGS AND CONGRESSES.

The facilities afforded by the Museum for meetings were in greater demand than usual for governmental and scientific gatherings and were fully utilized until the latter part of October, when the committee rooms were temporarily given over to the Bureau of War Risk Insurance. Meetings continued to some extent to be held in the auditorium until the last of December, when all engagements of accommodations were canceled, and the auditorium was also placed at the disposal of that bureau.

The Washington Society of the Fine Arts, as customary, was granted the auditorium for its lecture courses for the season, but held only five at the Museum. One of the committee rooms was assigned to the Anthropological Society of Washington and to the Federal Photographic Society for their regular meetings for the winter. The former used it but once, holding four other assemblies in the auditorium, and the Photographic Society went elsewhere, though it used the auditorium twice in July for exhibitions of motion pictures.

The American Public Health Association held a three-day session in the auditorium, on health problems and opportunities of the war, with a reception on the opening night, and the Medical Society of the District of Columbia celebrated its centennial anniversary by an afternoon meeting there.

The facilities of the Museum were used by various Government departments for conferences (1) to formulate plans for the production and conservation of the live-stock industry of the United States, (2) in the interest of fall wheat and rye planting, (3) of State agents on home demonstration work in the South, and (4) on home economics; for the pathological seminar of the Bureau of Plant Industry; for a lecture on horticultural work in China; for a meeting of the women employees of the Department of Agriculture to discuss

participation in war activities; for a second liberty loan meeting of Post Office Department employees; for two exhibitions of motion pictures relating to Army aeronautics for the Signal Corps of the United States Army; for a three-day school of instruction in the furtherance of the work of the United States Food Administration; and for lectures, on two occasions under the auspices of the National Council of Women, on one under the District of Columbia Chapter of the American Red Cross, and another under the Women's Liberty Loan Committee.

Before the auditorium was turned over to the Bureau of War Risk Insurance, that bureau frequently made use of it for instructing and organizing the field parties of officers and enlisted men who were to be sent to the various camps to attend to the details relating to the issuance of life insurance.

For two days the auditorium was given over to the annual meeting of the Potato Association of America, and the Bureau of Commercial Economics made use of it three times showing motion pictures of the war, to Army officers, on the first two occasions, and to members of the National Council of Defense on the last.

Besides the reception to the American Public Health Association on the evening of October 18, there was a reception in the National Gallery of Art on the occasion of the opening of the exhibition of lithographs of war work by Joseph Pennell on the evening of November 1.

MISCELLANEOUS.

Over 8,000 duplicate specimens, included in 8 regular sets of mollusks, 5 regular sets of fossil invertebrates, and a number of special sets, were distributed to schools and colleges. Exchanges for securing additions to the collections involved the use of about 23,227 duplicates, while more than 11,000 specimens, chiefly botanical and zoological, were lent to specialists for study.

The attendance of visitors at the natural history building aggregated 306,003 persons for week days and 95,097 for Sundays, being a daily average of 977 for the former and 1,828 for the latter. At the arts and industries building and the Smithsonian building, which are open only on week days, the totals were, respectively, 161,298 and 67,224, and the daily averages 515 and 214.

The publications of the year consisted of the annual report, one volume of proceedings, one volume of the contributions from the National Herbarium, and three bulletins, besides 40 separate papers. The latter comprised 28 from the proceedings, 4 from the contributions, 7 parts of bulletins, and a catalogue of a special loan collection in the National Gallery of Art.

The library obtained, by purchase, gift, and exchange, 6,162 volumes, 42 parts of volumes, and 1,541 pamphlets. The more important donations were the library of Biltmore Herbarium, and a large series of pharmaceutical works transferred from the Hygienic Laboratory.

Respectfully submitted.

W. DE C. RAVENEL,
Administrative Assistant.

Dr. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

OCTOBER 31, 1918.

APPENDIX 2.

REPORT ON THE BUREAU OF AMERICAN ETHNOLOGY.

SIR: Pursuant to your request of July 3, I have the honor to submit the following report on the operations of the Bureau of American Ethnology during the fiscal year ended June 30, 1918, conducted in accordance with the act of Congress approved June 12, 1917, making provisions for the sundry civil expenses of the Government, and in accordance with a plan of operations submitted by the ethnologist-in-charge and approved by the Secretary of the Smithsonian Institution. The act referred to contains the following item:

American ethnology: For continuing ethnological researches among the American Indians and the natives of Hawaii, including the excavation and preservation of archaeological remains, under the direction of the Smithsonian Institution, including necessary employees and the purchase of necessary books and periodicals, \$42,000.

The administrative affairs of the bureau prior to March 1, 1918, were conducted by Mr. F. W. Hodge, ethnologist-in-charge, when he resigned to accept a position in the Museum of the American Indian (Heye Foundation). On that date Dr. J. Walter Fewkes was appointed chief, and continued the administrative duties of the office to the close of the year.

As the American Indian is rapidly losing many of his instructive characteristics in his amalgamation into American citizenship, new features of the future work of the bureau stand out prominently pleading for investigation. Among these is the urgent necessity to rescue linguistic, sociological, and mythological data of aboriginal Indian life before its final extinction. When data now available disappear, unless recorded, they are lost forever.

The excavation and repair for preservation of archeologic remains, by no means a new activity of bureau work, is in the same condition. Both anthropology and popular approval call for the advancement and diffusion of knowledge by the bureau along this line.

In addition to their duties in "continuing ethnological researches" among the American Indians the members of the staff have devoted much time to matters germane to their work. Answers to many letters received by the bureau can not be written offhand, but demand investigation and often considerable consultation of authorities in the library. Their requests are not confined to Indian ethnology, but include a wide variety of questions on race mixture in the United

States, Old World anthropology, and the like. Although the staff is made up of experts in the study of the American Indians and the appropriation is limited to the study of our aborigines, the chief has not shrunk from the necessity of contributing what information he could on these related subjects, recognizing the need in the near future of a Bureau of Ethnology.

The "ethnological researches" of individual members of the staff the past year are outlined in the following pages.

At the close of the last fiscal year Mr. F. W. Hodge had begun excavations at Hawikuh, one of the "Seven Cities of Cibola," situated near the present pueblo of Zuñi, N. Mex. This work was continued in the summer months and yielded a large and varied collection of artifacts, which are now in the Museum of the American Indian (Heye Foundation).

The excavations were confined to the great refuse heaps that cover the western side of the elevation on which the ruins are situated, the maximum height of the hillock being 60 feet above the eastern valley. It was believed that this refuse would be found to follow the configuration of a gradual slope, but this proved not to be the case, for the farther the excavation was carried toward the ruined walls on the summit the deeper the refuse was found to be, and continuous work for nearly three months in this direction failed to reach a natural slope or escarpment.

The removal of the refuse, which had reached a depth of 15 feet when the work was suspended for the season, brought to light many features of interest, for, as was expected from the character of the surface soil, this great deposit of débris, consisting largely of ash and other refuse from the dwellings, interspersed with quantities of broken pottery and other artifacts, strata of drift sand, building refuse, etc., formed one of the cemeteries of the pueblo, or, one might say, the western area of a single great cemetery that surrounded the pueblo which, with its appurtenances, covers an area of approximately 756 by 850 feet, or nearly 15 acres. Excavation of perhaps a fifth of the cemetery area resulted in uncovering 237 graves.

Excavation had not proceeded very far before remains of walls of dwellings much older than those of historic Hawikuh were encountered on the floor of the original surface, 15 feet below the maximum deposit of refuse; yet, as the work progressed, it was found that these walls had been built over and across the walls of other and more ancient houses that had been erected, occupied, abandoned, and filled in to afford space for the construction of the dwellings which in turn preceded Hawikuh probably by many generations. The masonry of these earlier structures, on the whole, was much cruder than that of Hawikuh proper; but if allowance be made for disturbance caused by the burial of the dead through several generations, which

included more or less comparatively recent pottery in the lower levels, the earthenware of the earliest inhabitants of the site is of finer quality and of finer decoration than that manufactured by the historic Hawikuh people not long before the abandonment of their settlement.

Although the study of the archeology of Hawikuh has been barely commenced, the results of last season's work give promise of a material addition to our knowledge of an important phase of Pueblo culture, and it is hoped will ultimately open the way to the solution of related problems in southwestern archeology.

Besides the routine work of his desk Mr. Hodge gave what spare time he could while in Washington to continuing his work on the bibliography of the Pueblo Indians.

During July and August Dr. J. Walter Fewkes, ethnologist, completed his report on the Heye collection of West Indian antiquities and in the autumn made a brief archeological reconnoissance in southwestern Colorado, returning to Washington the middle of November. His plan of operations was to visit the ruins in the McElmo district and determine their architectural features in order to define with greater exactness the characteristics they share with the cliff dwellings and pueblos of the Mesa Verde National Park. The object was to gather material that would enable him to construct a classification of the prehistoric buildings of the Southwest from structural data. The Mesa Verde cliff dwellings and pueblos belong to a type or group of ruins distinguished by the structure of the roof and other features of the ceremonial room or kiva. The aim of the field work in 1917 was to investigate the distribution of this form of kiva and to discover other peculiarities of the Mesa Verde type or group at points remote from the plateau and thus enlarge our knowledge of the geographical distribution of the types.

It was found that the ruins in Montezuma Valley and the McElmo and its tributaries show extensions westward of the Mesa Verde type, and as the field work progressed much was added to our knowledge of the characteristics of great houses and towers, the examples of which on the Mesa Verde have been little investigated.

The most noteworthy group of the ancient ruins visited in the course of his field work were three clusters of great houses, castles, and towers situated a short distance over the State line on the northern tributaries of the canyons of the McElmo.

The most important result of the field work in 1917 is the conclusion that the ruins of the McElmo region indicate a people allied to those of Mesa Verde, who reached a high degree of architectural technique, surpassing any in America north of Mexico. Evidence was gathered that it was preceded by a stage indicated by one-house construction, and the suggestion is made that it antedated pueblos, on

which account it has been designated a middle phase in the Southwest. A considerable number of small ruins of the same structural type but with only one room were discovered in the tributaries of the McElmo and Dolores Rivers.

As a sequel to the exploration of the great houses, towers, and pueblos of Square Tower, Holly, and Hackberry Canyons, at the suggestion of Dr. Fewkes, the Director of the Public Park Service, Department of the Interior, has taken steps to have the ruins on these and adjacent canyons set aside from the public domain as a reserve, to be called the Hovenweep National Monument.

During the year Mr. James Mooney, ethnologist, remained in the office, engaged, as impaired health permitted, in the elaboration of his Cherokee sacred formulas. Throughout the winter and spring months much of his time was given to assisting the various delegations from the tribes of his working acquaintance, in the West, in their efforts before Congress, particularly in regard to their native Peyote religion, of which he has made a special study. The proof of friendship in the assistance thus given has completely won the hearts of the tribes concerned, and has opened the door to successful investigation along every line of inquiry.

On June 28 he left Washington for an extended stay with the Kiowa and associated tribes, among whom he is now at work.

During the past year, Dr. John R. Swanton, ethnologist, has devoted the greater part of his time to a study of three languages formerly spoken on and near the lower course of the Mississippi River—the Tunica, Chitimacha, and Atakapa (or Attacapa). The results of this study have been embodied in four papers—sketches of the grammars of the three languages in question, and a comparative study. A sketch of the Tunica language, covering about 70 typewritten pages, has been accepted for publication in the *International Journal of American Linguistics*. The sketch of Atakapa, of 40 or 50 pages, is practically complete and is designed for publication in the same journal; that of Chitimacha covers about 100 pages. The latter is withheld from publication for the present so that more material may be added. Finally, the paper in which the three languages are compared and the conclusion drawn that they belong in reality to but one linguistic stock, is to be published as a bulletin by this bureau. This covers about 70 typewritten pages.

During the latter half of April and all of May Dr. Swanton was engaged in field work in Louisiana, Mississippi, and South Carolina. In the first-mentioned State he continued his investigation of the Chitimacha language. His visit to Mississippi was principally for the purpose of inquiring into the social organization of the Choctaw still living there. In South Carolina he began a study of the Catawba language, with the help of manuscript material left by Dr. Gatschet,

and he plans to continue this study during the coming year. It is important as the only well-preserved dialect of any of the eastern Siouan peoples and that upon which must be based most of the relationship of the eastern Siouans to the other divisions of the stock. A small amount of ethnological material along other lines was also collected from the Chitimacha and the Catawba.

Dr. Swanton has also added some material to his history of the Creek Indians.

In July, 1917, Mr. J. N. B. Hewitt, ethnologist, began a critical and comparative study of the Cayuga texts relating to the Iroquois Federation, which he had recorded during the two previous field trips. This manuscript matter aggregates more than 500 pages and treats of more than 40 topics or features of the Federation of the Iroquois, dealing with the principles and structure of this institution of the Five "Nations" or tribes.

This comparative study was carried to tentative completion and involved not only the critical reading of the 500 pages of Cayuga text, but also an equal number of pages of Mohawk and Onondaga texts.

Mr. Hewitt also read 200 galleys of proofs of the Seneca myths and tales of the Thirty-second Annual Report of the Bureau of American Ethnology, of which 20 were of native texts with interlinear translations; he added to them nearly 200 numbered explanatory notes and read also 632 pages of the first and second revises for this same report, of which 100 pages are in native text with interlinear translations.

During May and June, 1918, Mr. Hewitt was engaged in field work in Ontario, Canada, among the Indians of the Six Nations of Iroquois. He took up the work in textual and literary criticism of the many texts he has recorded relating directly to the institution of the Federation or League of the Five Tribes or Nations in earlier field operations.

By far the largest, and also the most trustworthy, part of these texts was recorded from the dictation of one of the best-informed ritualists and expounders of the league, but much additional and supplementary matter in the form of texts was recorded from the dictation of other informants who had the reputation in the community of being authorities in regard to the motives and plans of the founders of the federation or league and the decrees and ordinances promulgated by them; but as these texts were given from memory it was inevitable that some of the most important details of the structure and working apparatus of the league have not been remembered with the same fidelity by different persons, and so various views and statements concerning the same subject matter are found. The problem for the student, then, is to ascertain by an adequate investigation upon what facts these conflicting views and statements were originally based. The vocabulary of the national terms employed is

that of statecraft and ritualism—the utterances of the statesmen and stateswomen of that earlier time, who had clear visions of institutions which are to-day being formulated and written into the statutes of our great republic. Among these may be mentioned the recall, the initiative, the referendum, a full-fledged colonial policy, and woman suffrage (limited to mothers), men having no voice in the body which nominates their chiefs.

It is well-nigh impossible to find an interpreter among the Iroquois who is such a master of both the English and the native Iroquoian languages as to be able to translate correctly a large number of the most important native terms into the English tongue. The following may be taken as a typical example. Dekanawida, in detailing the work of the founders in his "farewell address," used the following term frequently, and it also occurs elsewhere. This word is "We'dwěnnă'keră'dă'nyoñ'." The literal meaning is "We have made types or symbols of things." This is the only rendering known to most native interpreters. But its technical signification is "We have made ordinances, or laws, or regulations."

Another form of criticism is the discovery of the reasons which led to the variation of the ritual as used by the father and mother sides of the league. As an example the following may be cited. One or the other of these sides is the mourning side in the council of condolence and installation. The side which is not the mourning side employs all fourteen of the sections of the "Requickenings address." But it is customary for the mourning side, in replying, to employ only thirteen, omitting the ninth, which refers to the caring for the grave of the dead chieftain. This omission may seem to be a small matter to solve, but it is one which brings out the intense esoterism and metaphoric use of terms that characterize terminology of the institutions of the federation or league of the five nations or tribes of the Iroquois.

This definition or meaning shows that the rules of procedure among the Iroquois Five Tribes were not the commands of an autocrat or tyrant, but rather the formulated wisdom of a body of peers, who owed their position to the suffrages of those who owned the titles to them, and that the form of government was a limited democracy, or, strictly speaking, a limited gynecocracy.

At the beginning of the year Mr. Francis La Flesche, ethnologist, took up the task of putting together his notes on the "Wa-shá-be A-thiⁿ," a composite and intricate war ceremony of the Osage tribe. The name signifies the determination of the warrior who becomes a member of the ceremonially organized war party to show no mercy to the enemy and that he shall be even as the fire—a power that consumes all things that happen to be in its destructive course.

The literal translation of the name, Wa-shá-be Athiⁿ, is Wa-shá-be, a dark object; A-thiⁿ, to have in one's possession to carry. The word

"Wa-shá-be" is here used as a trope for the charcoal that symbolizes the merciless fire. The making of the symbolic charcoal forms an important part of the great ceremony and each warrior is required to carry with him a piece of this charcoal tied up in a little buckskin pouch. When he is about to attack the enemy he must blacken his face with this charcoal. If he happens to neglect this he will not be permitted to recount the strokes he may deliver the enemy in the attack and to count his war honors.

Originally there was only one "Wa-shá-be A-thi" ceremony and this ceremony pertained strictly to defensive and aggressive warfare. Later this ceremony was employed for organizing a war party to be sent out to slay some member of an enemy tribe in order to send the spirit of the slain man to overtake and accompany the spirit of the deceased member of the tribe and to be his companion to the realm of spirits.

The original ceremony was described by Wa-xthí-zhi, who belongs to the great division of the tribe which represents the earth and is called Hoⁿ-ga. The ceremony, when it is used as a mourning rite, was described by Xu-thá-wa-toⁿ-iⁿ, a member of the great division representing the sky, and called Tsí-zhu.

The account of these two ceremonies, the text, the songs, with their music, the recited parts of the ritual, and the illustrations and diagrams cover 253 pages.

It required much time as well as the exercise of patience to secure the details of these war ceremonies. Particularly was this true of the wí-gi-es (the recited parts), which relate to the traditions of the people, on account of their religious character and the superstitious awe with which the men and women of the tribe regarded them. Deaths have occurred during the study of these rites, and these deaths have been by the people attributed to the reciting of the rituals without regard to the traditional and prescribed rules.

In May, 1918, Mr. La Flesche visited the Osage Reservation for the purpose of completing his investigations of the tattooing rite, which he had started some time ago, and succeeded in securing 22 of the wí-gi-es (the recited parts) from one man at a continuous sitting of two days—a remarkable feat of memorizing. Each of these wí-gi-es belongs to a gens of the tribe, the male members of which recite it at an initiation into the mysteries of the rite or at the ceremony of the actual tattooing. All of these wí-gi-es are recited simultaneously by their owners, and the volume of sound is like that of a responsive reading in a church, with the difference that the reciting is not in unison, as each man recites for himself independently of the others. Fourteen of these wí-gi-es have been transcribed and translated, and they cover about 100 pages of hand-written manuscript.

Besides these 22 wí-gi-es, Mr. La Flesche secured the penalty wí-gi-es owned exclusively by the Thunder gens. He also obtained the penalty wí-gi-e owned in common by the various gentes of the Tsí-zhu division and the one owned by the gentes of the Wa-zhá-zhe and Ho"-ga subdivisions of the Ho"-ga great division. These penalty wí-gi-es are recited by their owners to the man who offers himself as a candidate for initiation into the mysteries of either the fasting or the shrine degree of the tribal rites. Like the "sword of Damocles," the penalty hangs over the head of the candidate and drops upon him the moment he violates his initiation obligations, and punishment comes to him by supernatural means. These two wí-gi-es have been transcribed, but are yet to be translated.

While in the office Dr. Truman Michelson, ethnologist, was engaged in correlating the Indian texts of the White Buffalo Dance with the English translation, and revising the latter. He left Washington near the middle of July and, arriving at Tama, Iowa, resumed his field work among the Sauk and Fox. His attention was mainly directed to the esoteric meaning of the songs of the White Buffalo Dance, and to verifying sociological work of the previous season. He obtained the names of nine-tenths of the Fox Indians and obtained information regarding the gens and dual divisions to which their owners belong. A number of ceremonies of these Indians were witnessed and he also learned some facts on Fox eschatology. During his work he purchased a number of sacred packs for the Museum of the American Indian (Heye Foundation), receiving the right to publish by the bureau the information pertaining to them. On leaving Tama, Dr. Michelson proceeded to Mayetta, Kans., to conduct a preliminary survey of the Potawatomi, as it was very clear that the dual divisions of the Sauk and Fox could only be thoroughly understood after that of the Potawatomi was unraveled. Although unable to completely work out the regulations governing membership in the Potawatomi dual divisions, he determined definitely that this division was for ceremonial as well as athletic purposes, as among the Sauk and Fox. He successfully studied the gentile organization of the Potawatomi and obtained a number of folk tales in English which show very clearly that a large body of European (French) element have been absorbed by the Potawatomi and that certain elements of the Plains Indians are present. To account for the distribution of the surviving tales we must assume an early association with the Ojibwa and a later one with the Sauk and Fox group, which is quite in line with what would be expected on linguistic and historic grounds. Dr. Michelson returned to Washington in October and prepared manuscript on a number of miscellaneous topics appertaining to the Fox Indians, to serve as an introduction to the proposed memoir on the White Buffalo Dance, which, with the excep-

tion of typewriting the Indian texts and the addition of a vocabulary, is now ready to submit for publication. During the winter Edward Davenport, a Fox pupil of the United States Indian School at Carlisle, spent a week in Washington, assisting in a number of points regarding the memoir.

In the spring Dr. Michelson made a preliminary translation of a Fox text of the "owl sacred pack." In June he went to Carlisle and worked out the dubious points in the translation with this informant, who dictated the Indian text twice from that in the current syllabary, so that the entire text is phonetically restored. The punctuation (with a few exceptions, added later at Tama) of the Indian text and English translation was harmonized.

Dr. Michelson edited Part I of Jones's Ojibwa Texts, containing about 50 pages, which were published by the American Ethnological Society, and collected the author's proofs of Part II, numbering 750, for a sketch of an Ojibwa grammar which will be offered for publication by the bureau.

Dr. Michelson has now in press an article in the *Journal of Linguistics* showing that the Pequot-Mohegan belong to the Natick group of the central division of the Algonquian language.

The beginning of the fiscal year found Mr. J. P. Harrington, ethnologist, in the field engaged in linguistic studies among the Mission Indians of Ventura County, Cal. At the close of this work, near the end of September, Mr. Harrington returned to Washington and spent the following months in the elaboration of recently collected material and his Tanoan and Kiowa notes.

Mr. Harrington has discovered a genetic relationship between the Uto-Aztecan, Tanoan, and Kiowa languages. The last two are so closely related that if the Kiowa had been spoken in New Mexico it would have been classed without hesitation by early writers as a Tanoan language. The Uto-Aztecan is more remotely but not less definitely related to the Kiowa genetically. The Kiowa sketch, amounting to 850 typewritten pages, now includes a complete analysis of all the important features of the language.

On June 9, 1918, Mr. Harrington proceeded to Anadarka, Okla., where he remained until June 26 revising for publication his entire sketch of the Kiowa language, after which he proceeded to Taos, N. Mex.

From July to August 15, 1917, Dr. Leo J. Frachtenberg was engaged in confidential war work for the Department of Justice (Bureau of Investigation). On his return to the bureau he continued his preliminary work on the grammar and mythology of the Kalapuya Indians of central Oregon begun during the previous fiscal year. He also continued his work of extracting, typewriting, and editing all Kalapuya texts collected by Dr. Gatschet. The myth-

ology of these Indians, who are almost extinct, constitutes a connecting link between the tribes of the coast and those east of the Rocky Mountains. While we possess numerous works dealing with the mythology of the Indians of the northwest coast and of the Great Plains, nothing has yet been published on the folklore of the tribes that inhabit the area between the Coast Range and the Rocky Mountains. Hence a volume on the mythology of the Kalapuya (and also Molala) Indians will be a welcome contribution to our knowledge of the folklore of the North American Indians.

SPECIAL RESEARCHES.

Dr. Franz Boas, honorary philologist, has been engaged in the correction of the proof of part 1 of his volume on the Kwakiutl-English, which has been assigned to the Thirty-fifth Annual Report.

For various reasons part 2 of the Handbook of American Indian Languages has been delayed.

Good progress has been made by Dr. Boas on the dialects and distribution of the Salish Tribe, much work having been done on the maps. This work, which is based on field work supported by Mr. Homer E. Sargent, was almost completed by Dr. Haeberlin, whose unfortunate death has somewhat curtailed the work on these tribes. A very important work on the basketry of the Salish Tribes, funds for which were also provided through the generosity of Mr. Sargent, has made good progress.

Prof. W. H. Holmes, of the National Museum, accompanied by Mr. DeLancey Gill, of the bureau, made a brief visit to the Aberdeen Proving Station, Maryland, where Indian remains had been reported in excavations for Government buildings. He also continued the preparation of the Handbook of American Antiquities, part 1 of which will soon be published as Bulletin 60 of the bureau.

Provision was made out of the appropriations of the Bureau of American Ethnology for a brief archeological reconnaissance in the Walhalla Plateau overlooking the Grand Canyon, from the last of April to the end of the fiscal year. Mr. Neil M. Judd, of the United States National Museum, was detailed for this work. He found remains of prehistoric buildings plentiful along the route of Kanab, Utah, southeastward, in the northern portion of the Kanab forest, at House Rock Valley, and in North, South, and Saddle Canyons. These remains consist usually of one, two, and three room structures constructed of unworked stone blocks. In many instances the foundations of the walls were stones placed on edge, their tops separating the masonry of the roof. Clusters of circular rooms, measuring from 4 to 10 feet in diameter, also occur. The floors of these rooms are generally covered with burnt earth or ashes, mingled with clay that bears impressions of willows and grass, as if parts of roofs similar

to those of prehistoric rooms observed along the Colorado River in the San Juan drainage.

Cliff houses also exist in the breaks bordering the Walhalla Plateau, but these are as a rule small single rooms, apparently cists for storage like those built by the people who inhabited the single-room houses in the open, somewhat back from the rim of the canyon. Many small artifacts were found on the cliffs but few fragments of pottery were reported.

Dr. Walter Hough was detailed from the National Museum to begin a study of the ruins in the Tonto Basin, a country of great archeological possibilities, situated between the valleys of the Little Colorado and the Gila. The result of a brief examination of the northern part of this region was encouraging, showing the existence of large ruins in the open as well as cliff houses of considerable size. Dr. Hough also made an examination of several important collections of artifacts, some of which are unique, and enumeration of the ruins visited by him indicates a promising field for future research, which it is the intention of the bureau to prosecute in coming seasons.

Mr. D. I. Bushnell, jr., continued the preparation of the manuscript for the Handbook of Aboriginal Remains East of the Mississippi. The introduction, containing much matter treating of sites, has been completed and will be published in advance of the handbook. It contains a valuable discussion of village sites and cemeteries, treated in a historical manner, with reproductions of old prints and maps.

Dr. A. L. Kroeber has elaborated certain portions of the Handbook of the Indians of California and little remains to be done before it is ready for publication.

The study of Indian music was continued by Miss Frances Densmore throughout the year. She has completed a report on the Ute music, consisting of about 375 pages, and has submitted new material on Ute, Mandan, and Chippewa music. Her account of the Mandan Hidatsa songs contains 400 pages. A new feature has been introduced in the study of the Ute melodies, where she has devised diagrams consisting of curves on a background of coordinate lines. Miss Densmore's main studies have been on ethnobotany of the Chippewa, and include plants used in treatment of the sick and other subjects. The general economic life and the industries of the people were also studied, during which she made an extensive collection, which she has photographed for use in her publications. She has likewise adopted the method of tone photographs designed by Dr. Dayton C. Miller, of the Case School of Applied Science, Cleveland, Ohio.

MANUSCRIPTS.

The following manuscripts, exclusive of those submitted for publication by the bureau, were purchased:

Unique copy of the Journal of Frederick Kurz's Travels through the Western States (in German). In addition to the text (in German) there are two jackets of photographs of original drawings of great historical value.

Six letters on British Guiana written by J. Henry Holmes to his wife, Mary Jane Holmes.

EDITORIAL WORK AND PUBLICATIONS.

On June 30, 1917, Mr. J. G. Gurley resigned his position as editor and Mr. Stanley Searles was appointed to the vacancy July 1. Both editors were assisted by Mrs. Frances S. Nichols. A report of the publication work of the bureau during the fiscal year follows:

Publications issued.

Bulletin 63.—Analytical and Critical Bibliography of the Tribes of Tierra del Fuego and Adjacent Territory, by John M. Cooper. 233 p., 1 pl.

Hawaiian Romance of Laieikawai.—By Martha Warren Beckwith. An advance separate from the Thirty-third Annual Report. 384 p., 5 pl.

Publications in press.

Thirty-second Annual Report.—Accompanying paper: Seneca Fiction, Legends, and Myths (Hewitt and Curtin).

Thirty-third Annual Report.—Accompanying papers: (1) Uses of Plants by the Indians of the Missouri River Region (Gilmore); (2) Preliminary Account of the Antiquities of the Region Between the Mancos and La Plata Rivers in Southwestern Colorado (Morris); (3) Designs on Prehistoric Hopi Pottery (Fewkes); (4) The Hawaiian Romance of Laieikawai (Beckwith).

Thirty-fourth Annual Report.—Accompanying paper: West Indian Antiquities in the Museum of the American Indian (Heye Foundation) (Fewkes).

Thirty-fifth Annual Report.—Accompanying paper: Ethnology of the Kwakiutl (Boas).

Bulletin 59.—Kutenai Tales (Boas).

Bulletin 60.—Handbook of Aboriginal American Antiquities—Part 1 (Holmes).

Bulletin 61.—Teton Sioux Music (Densmore).

Bulletin 64.—The Maya Indians of Southern Yucatan and Northern British Honduras (Gann).

Bulletin 65.—Archeological Explorations in Northeastern Arizona (Kidder and Guernsey).

Bulletin 66.—Recent Discoveries of Remains Attributed to Early Man in America (Hrdlička).

Bulletin 67.—Alsea Texts and Myths (Frachtenberg).

DISTRIBUTION OF PUBLICATIONS.

The distribution of the publications has been continued under the immediate charge of Miss Helen Munroe, assisted in the opening

months of the year by Miss Ora A. Sowersby, stenographer and typewriter, and later by Miss Emma B. Powers, Miss Sowersby having been transferred to the Bureau of American Ethnology.

Publications were distributed as follows:

	Copies.
Annual reports and separates.....	1, 766
Bulletins and separates.....	5, 460
Contributions to North American Ethnology (volumes and separates)....	7
Introductions.....	5
Miscellaneous publications.....	106
Total	7, 344

As compared with the fiscal year 1917, there was a decrease of 4,640 in the total number of publications distributed. This was due to the fact that during the fiscal year 1917 four publications were sent out to the mailing list, whereas in the fiscal year 1918 only Bulletin 63 was distributed to the list. Twenty addresses have been added to the mailing list during the year and 15 dropped, making a net increase of 5.

ILLUSTRATIONS.

Mr. De Lancey Gill, with the assistance of Mr. Albert E. Sweeney, continued the preparation of the illustrations required for the publications of the bureau and devoted the usual attention to photographing visiting Indians. A summary of this work is as follows:

Negatives of ethnologic and archeologic subjects.....	271
Photographic prints for distribution and office use.....	525
Photostat prints from books and manuscripts.....	300
Mounts used.....	800
Drawings and photographs prepared for publication as illustrations.....	517
Illustration proofs read.....	400
Portrait negatives of visiting Indians.....	15

LIBRARY.

The reference library of the bureau continued in the immediate care of Miss Ella Leary, assisted by Mr. Charles B. Newman.

There was presented to the library by Dr. J. Walter Fewkes the Codex Hopiensis, consisting of three bound volumes of colored pictures of Hopi Katchinas made by a Hopi Indian in 1900. This is the material on which was based the article "Hopi Katchinas" in the Twenty-first Annual Report of the Bureau of American Ethnology.

During the year 430 books were accessioned, of which 148 were acquired by purchase, 84 by binding periodicals, and 198 by gifts and exchanges. The periodicals currently received number about 760, of which 16 were received by subscription and 744 by gifts and exchange. We have also received 200 pamphlets, giving us at the close of the year a working library of 22,180 volumes, about 14,048 pamphlets, and several thousand periodicals.

During the year there were sent to the bindery 142 volumes, and 84 bound volumes were received.

In continuance of the policy of increasing the library by exchange and filling in incomplete sets, letters were written for new exchanges and for completing series already in the library. We have been able to secure by this means many valuable and important acquisitions.

In addition to the regular routine of cataloguing, classification, ordering from book dealers, making up for binding, and keeping the serial and accession records, the efforts of the librarian were devoted to making a subject, author, and analytical catalogue of books that are represented in the old catalogue under the author only.

During the year there was an increasing number of students not connected with the Smithsonian Institution who found the library of service in seeking volumes not obtainable in other libraries of the city. The library was used also by the Library of Congress and officers of the executive departments, and out-of-town students have called upon the library for loans during the year.

In addition to the use of its own library it was found necessary to draw on the Library of Congress from time to time for the loan of about 450 volumes. Numerous typewritten bibliographic lists have been made for correspondents of the bureau and the Smithsonian Institution.

The Monthly Bulletin for the use of the bureau staff has been continued throughout the year.

COLLECTIONS.

The following collections acquired by members of the staff of the Bureau, or by those detailed in connection with its researches, have been transferred to the U. S. National Museum:

Seven baskets made by the Koasati Indians of Louisiana, collected by Dr. John R. Swanton. (61315.)

A roughly chipped implement of gray limestone from British Guiana, presented by Dr. Walter E. Roth. (61325.)

Six ethnological specimens of the Mandan Sioux, Ute, and Chipewewa Indians, purchased from Miss Frances Densmore. (61573.)

A loom of the Osage Indians, collected by Mr. Francis La Flesche. (62013.)

Twelve specimens of plants from Minnesota, collected by Miss Frances Densmore. (62190.)

Twenty-five stone objects from the Huastec region, Mexico, presented to the bureau by Mr. John M. Muir, Tampico, Mexico. (62253.)

Arrowpoints, spearheads (18) collected by Dr. John R. Swanton in the vicinity of Rock Hill, S. C. (62577.)

PROPERTY.

Furniture was purchased to the amount of \$107.02; the cost of typewriting machines was \$175, making a total of \$282.02.

MISCELLANEOUS.

Quarters.—Two rooms on the third floor of the north tower of the Smithsonian Building, occupied by the bureau, were painted; also the office of the chief. A glass partition was erected on the south front of the space occupied by the librarian as an office, in order to render the office more comfortable during the winter months. Three enlarged photographs of Spruce-tree House, Mesa Verde National Park, before and after repair, were painted and hung in the office of the chief.

Personnel.—Changes in the personnel of the bureau during the last fiscal year were as follows:

Mr. F. W. Hodge, ethnologist in charge, resigned February 28, 1918, and Dr. J. Walter Fewkes succeeded him, with the title of chief, March 1, 1918. Dr. Leo J. Frachtenberg's official connection with the bureau terminated October 30, 1917. Mr. Stanley Searles was appointed editor July 1, 1917. Miss Florence M. Poast, clerk to Mr. Hodge, resigned October 15, 1917; Miss Ora A. Sowersby, a stenographer and typewriter in the service of the bureau, was assigned to that position November 1, 1918. The vacancy created by this change was filled by the appointment of Miss E. B. Powers, November 5, 1917.

Clerical.—The correspondence and other clerical work of the office, including the copying of manuscripts, has been conducted with the aid of Miss Florence M. Poast and Miss Ora A. Sowersby, clerks to the ethnologist in charge, and later by Miss M. S. Clark, serving as private secretary to the chief. Mrs. Frances S. Nichols assisted the editor.

Respectfully, yours,

J. WALTER FEWKES,
Chief.

DR. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

APPENDIX 3.

REPORT ON THE INTERNATIONAL EXCHANGES.

SIR: I have the honor to submit the following report on the operations of the International Exchange Service during the fiscal year ending June 30, 1918:

The estimate submitted by the Institution for carrying on the service during the year was \$35,000. This amount was granted by Congress, and, in addition, an allotment of \$200 was made for printing and binding. The various governmental departments and other establishments paid the Smithsonian Institution for the transportation of exchanges \$2,345.18, thus making the total available resources for carrying on the system of exchanges \$37,545.18.

The total number of packages handled during the year 1918 was 266,946. The weight of these packages was 182,825 pounds.

The number and weight of the packages of different classes are indicated in the following table:

	Packages.		Weight.	
	Sent.	Received.	Sent.	Received.
			<i>Pounds.</i>	<i>Pounds.</i>
United States parliamentary documents sent abroad.....	180,967		61,906	
Publications received in return for parliamentary documents.....		1,093		2,499
United States departmental documents sent abroad.....	51,506		50,634	
Publications received in return for departmental documents.....		1,981		3,373
Miscellaneous scientific and literary publications sent abroad..	23,026		40,509	
Miscellaneous scientific and literary publications received from abroad for distribution in the United States.....		8,373		23,904
Total.....	255,499	11,447	156,049	26,776
Grand total.....	266,946		182,825	

The disparity between the number of packages dispatched and those received is not so great as indicated by the figures in the foregoing table. Packages sent abroad usually contain only a single publication each, while those received in return often comprise several volumes. It is also a fact that many returns for publications sent abroad reach their destinations direct by mail and not through the exchange service.

So far as the Institution has been advised, only three consignments of exchanges have been lost through hostile action since the

beginning of the war. Information has been received from the Portuguese exchange service to the effect that the three boxes forwarded to that service in September, 1916, per steamship *Balto* were lost when that vessel was wrecked at sea. In reporting this loss the Portuguese exchange service does not state whether the vessel was sunk by the enemy.

The box of exchanges for the Jewish Agricultural Experiment Station, Haifa, Palestine, which the Egyptian Government publications office at Bulaq kindly agreed to hold until the cessation of hostilities, has been forwarded to its destination by that office. The attention given to this matter by the Government publications office and the trouble taken to reforward the consignment to its destination are much appreciated by the Institution.

New regulations adopted by the United States War Trade Board governing importations into the United States from Great Britain made it necessary for the Smithsonian agents in London to take out a consular invoice for shipments sent to the Institution, giving the full title of each book. The matter was brought to the attention of the Director of the Bureau of Imports of the War Trade Board, who very kindly issued a general license to cover the importation of international exchanges from the United Kingdom when consigned to the Smithsonian Institution. This action has not only resulted in expediting shipments from England, but has relieved the depleted force of the London Exchange Agency of a great deal of labor in connection with the forwarding of shipments to this country.

Aid has, as in previous years, been rendered to various governmental and scientific establishments in this and foreign countries in procuring desired publications. One instance in this connection may be referred to here. A request was received through diplomatic channels from the recently created French War Museum-Library, at Paris, for copies of American documents and other material relating to the war for deposit in a section of that library to be devoted to the part taken by the United States in the conflict. The Institution has taken the matter up with the several governmental establishments, and has received a number of publications for the above-mentioned library. Prof. Adolphe Cohn, of Columbia University, New York, is the American representative of the French War Museum-Library, and will take steps to procure publications and material from organizations outside of the Government.

Only 443 boxes of exchanges were forwarded abroad during the year. This does not represent an actual falling off in the number of packages distributed abroad, as many were sent to their destinations direct by mail. This method of transmission was adopted because it was found much cheaper to mail the packages than to forward them in boxes, owing to the great advance in ocean freight

rates. Of the total boxes transmitted 103 contained full sets of United States official documents to authorized depositories. The shipment of boxes containing the series of governmental documents was suspended during the latter half of the fiscal year, and will not be resumed until regular consignments are again forwarded to the distributing agencies.

The dates of transmission of the 443 boxes forwarded to foreign countries is shown in the following table:

Consignments of exchanges for foreign countries.

Country.	Number of boxes.	Date of transmission.
Argentina.....	18	Sept. 5, Nov. 3, 1917; Apr. 2, 1918.
Bolivia.....	1	Sept. 8, 1917.
Brazil.....	15	Sept. 5, Nov. 7, 1917; Apr. 8, 1918.
British colonies.....	4	July 28, Aug. 25, Oct. 3, Dec. 22, 1917.
British Guiana.....	1	Sept. 11, 1917.
Canada.....	16	Aug. 30, Nov. 21, 1917; Feb. 12, May 31, 1918.
Chile.....	11	Sept. 6, Nov. 9, 1917; Apr. 2, 1918.
China.....	13	Aug. 17, Oct. 5, Nov. 22, 1917; Mar. 31, 1918.
Colombia.....	9	Sept. 7, Nov. 12, 1917.
Costa Rica.....	2	Nov. 14, 1917.
Cuba.....	4	Aug. 30, Nov. 21, 1917; Feb. 12, May 31, 1918.
Denmark.....	4	Aug. 4, 1917.
Ecuador.....	2	Sept. 8, 1917.
France.....	32	Aug. 2, Sept. 27, 1917.
Great Britain and Ireland.....	104	July 28, Aug. 25, Oct. 3, Dec. 22, 1917.
Guatemala.....	1	July 28, 1917.
Haiti.....	3	Sept. 7, Nov. 14, 1917; Apr. 1, 1918.
Honduras.....	1	Sept. 8, 1917.
India.....	11	July 28, Aug. 25, Oct. 3, Dec. 22, 1917.
Italy.....	26	Aug. 23, Oct. 20, Dec. 28, 1917.
Jamaica.....	1	Sept. 14, 1917.
Japan.....	31	Oct. 10, 1917; Jan. 8, May 7, 1918.
Mexico.....	4	Aug. 30, Nov. 21, 1917; Feb. 12, May 31, 1918.
New South Wales.....	18	Sept. 16, Nov. 13, 1917; Apr. 2, 1918.
New Zealand.....	9	Sept. 28, 1917; Nov. 21, Apr. 2, 1918.
Nicaragua.....	1	Sept. 8, 1917.
Paraguay.....	2	Do.
Peru.....	8	Sept. 8, Nov. 10, 1917; Apr. 2, 1918.
Portugal.....	4	Aug. 4, Oct. 16, 1917.
Queensland.....	4	Sept. 20, Nov. 21, 1917; Apr. 2, 1918.
Salvador.....	1	Sept. 8, 1917.
Siam.....	1	Sept. 12, 1917.
South Australia.....	11	Sept. 19, Nov. 17, 1917; Apr. 2, 1918.
Spain.....	12	Aug. 13, Oct. 12, 1917; Jan. 9, 1918.
Switzerland.....	5	Aug. 10, 1917.
Tasmania.....	5	July 28, Aug. 25, Dec. 22, 1917.
Union of South Africa.....	9	Aug. 18, Dec. 7, 1917.
Uruguay.....	10	Sept. 6, Nov. 10, 1917; Apr. 2, 1918.
Venezuela.....	6	Sept. 6, Nov. 12, 1917; Apr. 2, 1918.
Victoria.....	14	Sept. 18, Nov. 16, 1917; Apr. 15, 1918.
Western Australia.....	6	July 28, Aug. 23, Dec. 22, 1917.

FOREIGN DEPOSITORIES OF UNITED STATES GOVERNMENTAL DOCUMENTS.

Ninety-one sets of United States governmental documents were received during the year for distribution to the following depositories:

DEPOSITORIES OF FULL SETS.

- ARGENTINA: Ministerio de Relaciones Exteriores, Buenos Aires.
 AUSTRALIA: Library of the Commonwealth Parliament, Melbourne.
 AUSTRIA: K. K. Statistische Zentral-Kommission, Vienna.
 BADEN: Universitäts-Bibliothek, Freiburg. (Depository of the Grand Duchy of Baden.)
 BAVARIA: Königliche Hof- und Staats-Bibliothek, Munich.
 BELGIUM: Bibliothèque Royale, Brussels.
 BRAZIL: Bibliotheca Nacional, Rio de Janeiro.
 BUENOS AIRES: Biblioteca de la Universidad Nacional de La Plata. (Depository of the Province of Buenos Aires.)
 CANADA: Library of Parliament, Ottawa.
 CHILE: Biblioteca del Congreso Nacional, Santiago.
 CHINA: American-Chinese Publication Exchange Department, Shanghai Bureau of Foreign Affairs, Shanghai.
 COLOMBIA: Biblioteca Nacional, Bogotá.
 COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.
 CUBA: Secretaria de Estado (Asuntos Generales y Canje Internacional), Habana.
 DENMARK: Kongelige Bibliotheket, Copenhagen.
 ENGLAND: British Museum, London.
 FRANCE: Bibliothèque Nationale, Paris.
 GERMANY: Deutsche Reichstags-Bibliothek, Berlin.
 GLASGOW: City Librarian, Mitchell Library, Glasgow.
 GREECE: Bibliothèque Nationale, Athens.
 HAITI: Secrétaire d'État des Relations Extérieures, Port au Prince.
 HUNGARY: Hungarian House of Delegates, Budapest.
 INDIA: Imperial Library, Calcutta.
 IRELAND: National Library of Ireland, Dublin.
 ITALY: Biblioteca Nazionale Vittorio Emanuele, Rome.
 JAPAN: Imperial Library of Japan, Tokyo.
 LONDON: London School of Economics and Political Science. (Depository of the London County Council.)
 MANITOBA: Provincial Library, Winnipeg.
 MEXICO: Instituto Bibliográfico, Biblioteca Nacional, Mexico.
 NETHERLANDS: Library of the States General, The Hague.
 NEW SOUTH WALES: Public Library of New South Wales, Sydney.
 NEW ZEALAND: General Assembly Library, Wellington.
 NORWAY: Stortingets Bibliothek, Christiania.
 ONTARIO: Legislative Library, Toronto.
 PARIS: Préfecture de la Seine.
 PERU: Biblioteca Nacional, Lima.
 PORTUGAL: Bibliotheca Nacional, Lisbon.
 PRUSSIA: Königliche Bibliothek, Berlin.
 QUEBEC: Library of the Legislature of the Province of Quebec, Quebec.
 QUEENSLAND: Parliamentary Library, Brisbane.

RUSSIA: Imperial Public Library, Petrograd.
SAXONY: Königliche Oeffentliche Bibliothek, Dresden.
SERBIA: Section Administrative du Ministère des Affaires Étrangères, Belgrade.
SOUTH AUSTRALIA: Parliamentary Library, Adelaide.
SPAIN: Servicio del Cambio Internacional de publicaciones, Cuerpo Facultativo de Archiveros, Bibliotecarios y Arqueólogos, Madrid.
SWEDEN: Kungliga Biblioteket, Stockholm.
SWITZERLAND: Bibliothèque Fédérale, Berne.
TASMANIA: Parliamentary Library, Hobart.
TURKEY: Department of Public Instruction, Constantinople.
UNION OF SOUTH AFRICA: State Library, Pretoria, Transvaal.
URUGUAY: Oficina de Canje Internacional de Publicaciones, Montevideo.
VENEZUELA: Biblioteca Nacional, Caracas.
VICTORIA: Public Library, Melbourne.
WESTERN AUSTRALIA: Public Library of Western Australia, Perth.
WÜRTTEMBERG: Königliche Landesbibliothek, Stuttgart.

DEPOSITORIES OF PARTIAL SETS.

ALBERTA: Provincial Library, Edmonton.
ALSACE-LORRAINE: K. Ministerium für Elsass-Lothringen, Strassburg.
BOLIVIA: Ministerio de Colonización y Agricultura, La Paz.
BREMEN: Senatskommission für Reichs- und Auswärtige Angelegenheiten.
BRITISH COLUMBIA: Legislative Library, Victoria.
BRITISH GUIANA: Government Secretary's Office, Georgetown, Demerara.
BULGARIA: Minister of Foreign Affairs, Sofia.
CEYLON: Colonial Secretary's Office (Record Department of the Library), Colombo.
ECUADOR: Biblioteca Nacional, Quito.
EGYPT: Bibliothèque Khédiviale, Cairo.
FINLAND: Chancery of Governor, Helsingfors.
GUATEMALA: Secretary of the Government, Guatemala.
HAMBURG: Senatskommission für die Reichs- und Auswärtigen Angelegenheiten.
HESSE: Grossherzogliche Hof-Bibliothek, Darmstadt.
HONDURAS: Secretary of the Government, Tegucigalpa.
JAMAICA: Colonial Secretary, Kingston.
LIBERIA: Department of State, Monrovia.
LOURENÇO MARQUEZ: Government Library, Lourenço Marquez.
LÜBECK: President of the Senate.
MADRAS, PROVINCE OF: Chief Secretary to the Government of Madras, Public Department, Madras.
MALTA: Lieutenant Governor, Valetta.
MONTENEGRO: Ministère des Affaires Étrangères, Cetinje.
NEW BRUNSWICK: Legislative Library, Fredericton.
NEWFOUNDLAND: Colonial Secretary, St. John's.
NICARAGUA: Superintendente de Archivos Nacionales, Managua.
NORTHWEST TERRITORIES: Government Library, Regina.
NOVA SCOTIA: Provincial Secretary of Nova Scotia, Halifax.
PANAMA: Secretaria de Relaciones Exteriores, Panama.
PARAGUAY: Oficina General de Inmigración, Asuncion.
PRINCE EDWARD ISLAND: Legislative Library, Charlottetown.
ROUMANIA: Academia Romana, Bucharest.
SALVADOR: Ministerio de Relaciones Exteriores, San Salvador.
SIAM: Department of Foreign Affairs, Bangkok.

STRAITS SETTLEMENTS: Colonial Secretary, Singapore.

UNITED PROVINCES OF AGRA AND OUDH: Under Secretary to Government, Allahabad.

VIENNA: Bürgermeister der Haupt- und Residenz-Stadt.

INTERPARLIAMENTARY EXCHANGE OF OFFICIAL JOURNALS.

A complete list of the countries which have entered into the Interparliamentary Exchange of Official Journals with the United States is given below. The Congressional Records for those countries to which it is not possible to forward consignments at present are being held at the Institution.

Argentine Republic.	France.	Prussia.
Australia	Great Britain.	Queensland.
Austria.	Greece.	Roumania.
Baden.	Guatemala.	Russia.
Belgium.	Honduras.	Serbia.
Bolivia.	Hungary.	Spain.
Brazil.	Italy.	Switzerland.
Buenos Aires, Province of.	Liberia.	Transvaal.
Canada.	New South Wales.	Union of South Africa.
Costa Rica.	New Zealand.	Uruguay.
Cuba.	Peru.	Venezuela.
Denmark.	Portugal.	Western Australia.

FOREIGN EXCHANGE AGENCIES.

Consignments for India, instead of being forwarded through the India Office in London as formerly, are now sent directly to the Superintendent of Stationery at Bombay, which has been designated as the establishment to undertake the distribution of exchanges in that country. This change was made at the request of the Under-Secretary of State for India in London.

Below is given a complete list of the foreign exchange agencies and bureaus:

ALGERIA, *via* France.

ANGOLA, *via* Portugal.

ARGENTINA: Comisión Protectora de Bibliotecas Populares, Santa Fé 880, Buenos Aires.

AUSTRIA: K. K. Statistische Zentral-Kommission, Vienna.

AZORES, *via* Portugal.

BELGIUM: Service Belge des Échanges Internationaux, Rue des Longs-Chariots 46, Brussels.

BOLIVIA: Oficina Nacional de Estadística, La Paz.

BRAZIL: Serviço de Permutações Internacionais, Bibliotheca Nacional, Rio de Janeiro.

BRITISH COLONIES: Crown Agents for the Colonies, London.

BRITISH GUIANA: Royal Agricultural and Commercial Society, Georgetown.

BRITISH HONDURAS: Colonial Secretary, Belize.

BULGARIA: Institutions Scientifiques de S. M. le Roi de Bulgarie, Sofia.

CANARY ISLANDS, *via* Spain.

CHILE: Servicio de Canjes Internacionales, Biblioteca Nacional, Santiago.

CHINA: American-Chinese Publication Exchange Department, Shanghai Bureau of Foreign Affairs, Shanghai.

COLOMBIA: Oficina de Canjes Internacionales y Reparto, Biblioteca Nacional, Bogotá.

COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.

DENMARK: Kongelige Danske Videnskabernes Selskab, Copenhagen.

DUTCH GUIANA: Surinaamsche Koloniale Bibliotheek, Paramaribo.

ECUADOR: Ministerio de Relaciones Exteriores, Quito.

EGYPT: Government Publications Office, Printing Department, Cairo.

FRANCE: Service Français des Échanges Internationaux, 110 Rue de Grenelle, Paris.

GERMANY: Amerika-Institut, Berlin, N. W. 7.

GREAT BRITAIN AND IRELAND: Messrs. William Wesley & Son, 28 Essex Street, Strand, London.

GREECE: Bibliothèque Nationale, Athens.

GREENLAND, *via* Denmark.

GUADELOUPE, *via* France.

GUATEMALA: Instituto Nacional de Varones, Guatemala.

GUINEA, *via* Portugal.

HAITI: Secrétaire d'État des Relations Extérieures, Port au Prince.

HONDURAS: Biblioteca Nacional, Tegucigalpa.

HUNGARY: Dr. Julius Pikler, Municipal Office of Statistics, Váci-utca 80, Budapest.

ICELAND, *via* Denmark.

INDIA: Superintendent of Stationery, Bombay.

ITALY: Ufficio degli Scambi Internazionali, Biblioteca Nazionale Vittorio Emanuele, Rome.

JAMAICA: Institute of Jamaica, Kingston.

JAPAN: Imperial Library of Japan, Tokyo.

JAVA, *via* Netherlands.

KOREA: Government General, Keijo.

LIBERIA: Bureau of Exchanges, Department of State, Monrovia.

LOURENÇO MARQUEZ: Government Library, Lourenço Marquez.

LUXEMBURG, *via* Germany.

MADAGASCAR, *via* France.

MADEIRA, *via* Portugal.

MONTENEGRO: Ministère des Affaires Étrangères, Cetinje.

MOZAMBIQUE, *via* Portugal.

NETHERLANDS: Bureau Scientifique Central Néerlandais, Bibliothèque de l'Université, Leyden.

NEW GUINEA, *via* Netherlands.

NEW SOUTH WALES: Public Library of New South Wales, Sydney.

NEW ZEALAND: Dominion Museum, Wellington.

NICARAGUA: Ministerio de Relaciones Exteriores, Managua.

NORWAY: Kongelige Norske Frederiks Universitet Bibliotheket, Christiania.

PANAMA: Secretaria de Relaciones Exteriores, Panama.

PARAGUAY: Servicio de Canje Internacional de Publicaciones, Sección Consular y de Comercio, Ministerio de Relaciones Exteriores, Asuncion.

PERSIA: Board of Foreign Missions of the Presbyterian Church, New York City.

PERU: Oficina de Reparto, Depósito y Canje Internacional de Publicaciones, Ministerio de Fomento, Lima.

PORTUGAL: Serviço de Permutações Internacionais, Inspeção Geral das Bibliotecas e Archivos Publicos, Lisbon.

QUEENSLAND: Bureau of Exchanges of International Publications, Chief Secretary's Office, Brisbane.

ROUMANIA: Academia Romana, Bucharest.

RUSSIA: Commission Russe des Échanges Internationaux, Bibliothèque Impériale Publique, Petrograd.

SALVADOR: Ministerio de Relaciones Exteriores, San Salvador.

SERBIA: Section Administrative du Ministère des Affaires Étrangères, Belgrade.

SIAM: Department of Foreign Affairs, Bangkok.

SOUTH AUSTRALIA: Public Library of South Australia, Adelaide.

SPAIN: Servicio del Cambio Internacional de Publicaciones, Cuerpo Facultativo de Archiveros, Bibliotecarios y Arqueólogos, Madrid.

SUMATRA: *via* Netherlands.

SWEDEN: Kongliga Svenska Vetenskaps Akademien, Stockholm.

SWITZERLAND: Service des Échanges Internationaux, Bibliothèque Fédérale Centrale, Berne.

SYRIA: Board of Foreign Missions of the Presbyterian Church, New York.

TASMANIA: Secretary to the Premier, Hobart.

TRINIDAD: Royal Victoria Institute of Trinidad and Tobago, Port-of-Spain.

TUNIS, *via* France.

TURKEY: American Board of Commissioners for Foreign Missions, Boston.

UNION OF SOUTH AFRICA: Government Printing Works, Pretoria, Transvaal.

URUGUAY: Oficina de Canje Internacional, Montevideo.

VENEZUELA: Biblioteca Nacional, Caracas.

VICTORIA: Public Library of Victoria, Melbourne.

WESTERN AUSTRALIA: Public Library of Western Australia, Perth.

WINDWARD AND LEEWARD ISLANDS: Imperial Department of Agriculture, Bridgetown, Barbados.

Respectfully submitted.

C. W. SHOEMAKER,
Chief Clerk, International Exchange Service.

DR. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

AUGUST 26, 1918.

APPENIDX 4.

REPORT ON THE NATIONAL ZOOLOGICAL PARK.

SIR: I have the honor to present the following report on the operations of the National Zoological Park for the fiscal year ending June 30, 1918:

The sum of \$100,000 was provided by Congress in the sundry civil act for all expenses except printing and binding, for which an additional allotment of \$200 was made. Virtually the entire appropriation was needed for actual maintenance, the cost of which continues to increase from year to year, and only small sums could be expended on necessary repairs or minor permanent improvements. There has been difficulty throughout the year in keeping the required number of employees in all departments of the force, while the resources of the park have been taxed to the utmost to care properly for the greatly increased number of visitors. Notwithstanding the difficulties of the wild-animal trade and the great reduction in the number of specimens reaching this country from abroad, the collections have been kept up to a fair standard in numbers without serious gaps, and the popular and scientific value of the exhibition has not been impaired.

ACCESSIONS.

Gifts.—There were added to the collection by gift a total number of 103 animals. The list includes many valuable and important accessions, among them several species not previously exhibited in the park.

The first specimen of the glacier bear (*Ursus emmonsii*) ever known to have been captured alive was received at the park July 25, 1917, as a gift from Mr. Victor J. Evans, of Washington, D. C., who has made many donations to the collection in past years. The glacier bear, or blue bear as it is sometimes called, has a very limited distribution in the region of the St. Elias Alps, near Yakutat Bay, Alaska. It was first described in 1895 and since that time only one or two skins have been brought into Yakutat by the Indians each year. The specimen secured by Mr. Evans was captured as a small cub by an Indian at the head of Disenchantment Bay, a continuation of Yakutat Bay, about the middle of May, 1916, and was soon after sold to a trader in Yakutat. As one of the rarest and least known of the

great game animals of America, the glacier bear has, since its discovery, been watched for eagerly by the officials of zoological gardens.

The New Zealand Government, through Mr. Ben Wilson of the Department of Tourist and Health Resorts, made to the park the most valuable gifts of birds received during the year. These included six keas, or sheep-killing parrots (*Nestor notabilis*), and eight wekas, or flightless rails (*Ocydromus*) from South Island, New Zealand. The keas are beautiful and interesting parrots of large size which inhabit the high mountains of New Zealand. Some individuals of the species have developed the habit of killing sheep, and as a consequence the birds have been greatly reduced in numbers by the stockmen. A large outdoor cage with shelter attached was constructed near the bird house and the keas have attracted great attention. They are utterly unmindful of the cold, and during the unusually severe weather of last winter they played in the snow and bathed in icy water. The wekas, of which three species are represented in the collection, are members of the group of rails notable for their imperfectly developed wings. They are of the size of a well-grown pullet and are mischievous and quarrelsome even among others of their kind. Unlike their relatives in North America they are not aquatic, but inhabit dry woods and scrub.

Two interesting collections of Trinidad snakes were received from Mrs. James Birch Rorer and from Hon. Henry D. Baker, Trinidad, British West Indies. Included in the lot from Mr. Baker was a large boa constrictor nearly 11 feet in length.

Among the miscellaneous donations for the past year were some valuable parrots from individuals as noted below. Not less than six species of amazons, of which the white-fronted (*Amazona albifrons*), yellow-cheeked (*Amazona autumnalis*), and Santo Domingo (*Amazona ventralis*) were new to the collection, were received in this manner. The Brazilian green macaw and Haitian paroquet were also previously unrepresented.

The complete list of donors and gifts is as follows:

- Mr. Norman Anderson, Washington, D. C., alligator.
- Mr. G. Gordon Bailey, Washington, D. C., red-tailed hawk.
- Hon. Henry D. Baker, Trinidad, British West Indies, boa constrictor, tree boa, three lora snakes, and three water coral snakes.
- Mrs. Barefield, Washington, D. C., Cuban parrot.
- Mr. J. Barnes, Washington, D. C., alligator.
- Maj. E. R. Beadle, Paris Island, S. C., peacock.
- Miss Pearl Beard, Herndon, Va., American crow.
- Mr. William Blum, Chevy Chase, Md., opossum.
- Mr. S. Howe Bonar, Moundsville, W. Va., great horned owl.
- Mr. C. F. Borden, Brookland, D. C., white-fronted parrot.
- Mr. J. T. Boston, Washington, D. C., American coot.
- Mrs. J. Bourke, Washington, D. C., two alligators.
- Mrs. C. V. Brooks, Del Ray, Va., alligator.

- Mr. Bobby Bulkley, Chevy Chase, D. C., alligator.
 Mr. Willard Burton, Washington, D. C., alligator.
 Camp Meigs Band, Quartermaster Corps, United States Army, Washington, D. C., turkey.
 Mr. James L. Chase, Washington, D. C., yellow-cheeked parrot.
 Mr. Waldo A. Clarke, Washington, D. C., opossum.
 Miss Pauline Corson, Guinea Mills, Va., raccoon.
 Mrs. M. B. Crawford, Washington, D. C., yellow-headed parrot and two double yellow-head parrots.
 Mr. Ernest W. Davis, Asheville, N. C., Margarita capuchin.
 Department of Tourist and Health Resorts, New Zealand Government, through Mr. Ben Wilson, six kea parrots and eight weka rails.
 Mr. Victor J. Evans, Washington, D. C., glacier bear.
 Mr. L. R. Grabill, Takoma Park, D. C., alligator.
 Miss Catherine N. Hinton, Petersburg, Va., white-throated capuchin.
 Mr. A. B. Hodges, Washington, D. C., alligator.
 Mr. A. V. Hoffman, Washington, D. C., Brazilian green macaw.
 Lieut. C. D. Holland, Washington, D. C., two double yellow-head parrots.
 Mr. J. M. Horton, Washington, D. C., alligator.
 Mr. C. E. Hunt, Washington, D. C., two mourning doves.
 Mr. T. A. James, Augusta, Me., two black ducks.
 Mr. F. H. Johnson, Washington, D. C., two alligators.
 Mr. E. S. Joseph, Sydney, Australia, dingo, two Tasmanian phalangiers, two stump-tailed lizards, and three blue-tongued lizards.
 Mr. C. Herbert Kreh, Frederick, Md., copperhead.
 Krey, Price & Co., Washington, D. C., bald eagle.
 Miss F. I. Latham, Brookland, D. C., bobwhite.
 Mr. C. C. Lets, Chevy Chase, D. C., water snake.
 Mrs. Macklehaney, Washington, D. C., alligator.
 Mr. R. H. Macneil, Washington, D. C., alligator.
 Mr. William M. Mann, Washington, D. C., crocodile.
 Mrs. John H. McChesney, Washington, D. C., Haitian paroquet and Santo Domingo parrot.
 Mrs. F. McManamy, Chevy Chase, Md., screech owl.
 Mrs. Thomas P. Morgan, Washington, D. C., Philippine macaque.
 Mr. H. A. O'Dwyer, Washington, D. C., barred owl.
 Mrs. Charles Parks, Washington, D. C., albino squirrel.
 Mr. A. H. Peterson, Washington, D. C., screech owl.
 Mr. J. S. Rector, McLean, Va., barred owl.
 Mrs. C. S. Rockwood, Washington, D. C., ring-necked duck.
 Mrs. James Birch Rorer, Trinidad, British West Indies, anaconda, lora snake, and slug-eating snake.
 Mr. Charles E. Schaffner, Washington, D. C., canvasback duck.
 Mr. Milford Schwartz, Washington, D. C., barred owl.
 Mrs. J. V. Shipp, Chevy Chase, D. C., Cuban parrot.
 Miss Marjorie Smith, Fort Meyer Heights, Va., alligator.
 Mrs. T. K. Smith, Washington, D. C., alligator.
 Mr. J. E. Taylor, Oxford, Md., red fox.
 Mr. Joseph Turner, Washington, D. C., black bear.
 Mrs. Frank Walter, Washington, D. C., yellow-headed parrot.
 Mr. F. L. Waters, Washington, D. C., two alligators.
 Mr. Alexander Wetmore, Washington, D. C., American crow.
 Mr. Walter L. Whitney, Takoma Park, D. C., coyote.
 Mr. Bertram Wills, Washington, D. C., two alligators.

Hon. Woodrow Wilson, Washington, D. C., turkey.

Mr. Nelson R. Wood, Washington, D. C., cedar waxwing.

Mr. E. S. Wright, Lassiter, Va., black-crowned night heron.

In addition to the vertebrate animals listed above and regularly catalogued in the collection, a most interesting exhibit of crabs was maintained throughout most of the year. The specimens were presented by the collector, Dr. Paul Bartsch, of the National Museum, and comprised 69 West Indian hermit crabs (*Caenobita clypeata*) from Bush Key, and 37 West Indian land crabs (*Gecarcinus lateralis*) from Loggerhead Key, Dry Tortugas, Fla. Some specimens of the work of beavers, stumps and cuttings made by the animals in the construction of dams and lodges, were collected in the Adirondacks, and presented to the Park by Mr. W. E. Talmage, of Cleveland, Ohio. Arranged on a stand constructed for the purpose in the beaver inclosure, they have added greatly to the interest of the public in this animal and its work.

Births.—Sixty-three mammals were born, and 45 birds were hatched during the year. The births include 1 Brazilian tapir, 1 yak, 2 bison, 2 Rocky Mountain sheep, 2 nilgais, 1 black buck, 2 guanacos, 3 llamas, 1 black-tailed deer, 1 Virginia deer, 1 Manchurian deer, 2 American elk, 5 red deer, 1 fallow deer, 4 axis deer, 2 hog deer, 4 Japanese deer, 1 barasingha deer, 4 great red kangaroos, 1 brush-tailed rock kangaroo, 1 rufous-bellied wallaby, 1 common phalanger, 2 Tasmanian phalangers, 4 raccoons, 9 coypus, 1 paca, 2 Peruvian wild guinea-pigs, and 2 rhesus monkeys. The birds hatched include Canada geese, wood ducks, mallards, East Indian black ducks, American coots, cormorants, night herons, and peafowls.

The tapir, born February 22, is the ninth young reared in the park since 1903 from a single pair of animals.

Exchanges.—In exchange for surplus animals born in the park there were received during the year 11 mammals, 25 birds, and 6 reptiles. Some valuable additions were made to the collections from this source, including a female Manchurian tiger, a young Himalayan bear, a blesbok, two striped hyenas, and a number of Australian mammals, birds, and reptiles. A pair of straw-necked ibises (*Caprimachus spinicollis*), the first of the species ever shown in the park, was received in May.

Purchases.—The only mammals purchased during the year were 12 prairie-dogs to restock the "dog town," the population of which had been greatly reduced in numbers, and one specimen of the Arizona mountain sheep. Birds to the number of 104, mostly waterfowl and small aviary species, were added to the collection by purchase. Perhaps the most noteworthy accession by purchase among the birds

is a pair of thick-billed parrots (*Rhynchopsitta pachyrhyncha*) from the Chiracahua Mountains of Arizona. This species is the only member of the order of parrots, excepting the almost extinct Carolina parakeet, known to occur within the United States. At intervals a number of years apart flights of thick-bills appear in the mountains of southern Arizona, coming from Mexico. The birds obtained for the park were captured in January in the pine forested Chiracahuas, when the ground in the higher altitudes where the birds occur was covered with snow. A single reptile, a rattlesnake, was purchased during the year.

Transfers.—The Biological Survey of the Department of Agriculture, as in the past, contributed to the collection by the transfer of a number of specimens captured by field agents of the bureau. Seven plains wolves, including one black wolf, were received from Montana, Wyoming, and Utah. From New Mexico the Biological Survey sent a specimen each of the western horned owl, ferruginous rough-leg hawk, and Abert's squirrel.

Captured in the park.—Three mammals, five birds, and one reptile captured within the boundaries of the park were added to the collection.

Deposited.—Mr. E. S. Joseph, of Sydney, New South Wales, deposited with the park in September, 1917, a specimen of the brown hyena (*Hyena brunnea*) of South Africa. The species is one of the rarest of mammals and had not heretofore been exhibited in Washington. It is now possible for the first time to compare in the collection living examples of the three distinct types of hyenas—the spotted, striped, and brown. Birds received on deposit and not otherwise represented in the collection are the Panama parrot (*Amazona farinosa inornata*) from Mrs. M. W. Gill, Washington, D. C., and the blue-winged parrotlet (*Psittacula passerina*) from Mr. W. J. La Varre, jr., Washington, D. C. Fur-bearing animals from the Biological Survey and eight alligators from the Pan-American Union were received on deposit during the year.

REMOVALS.

The following surplus animals were exchanged to other zoological gardens: Five aoudads, 1 tahr, 2 bison, 2 llamas, 2 guanacos, 1 Arabian camel, 5 red deer, 6 fallow deer, 2 Japanese deer, 2 axis deer, 1 Kashmir deer, 4 baboons, 1 monkey, 1 tiger, 1 raccoon, 13 coypus, 6 East Indian black ducks, 4 Canada geese, 3 peafowl, and 6 alligators. A few specimens on deposit were returned to owners.

Among the specimens lost by death were a few of the oldest exhibits in the park—animals that had been here for many years. The female Steller's sea-lion died of gastroenteritis on January 22. This fine specimen was received October 23, 1900, and had therefore been

in the park, in good health, for over 17 years. Its age at the time of arrival was uncertain, but it was probably over 2 years old. The Somaliland lioness, Duchess, which was received at the park December 17, 1902, when about 3 years old, from Hon. E. S. Cunningham, United States consul at Aden, died June 15, 1918, at an age of about 19 years, 15½ years of which had been spent in the park. It is extremely doubtful if a wild lion ever reaches so advanced an age. A male Brazilian tapir received from Commander C. C. Todd, United States Navy, May 19, 1899, died September 17, 1917, after a period of 18 years and 4 months of life in the park. Among the birds, a yellow-throated caracara (*Ibycter ater*) received from Hon. E. H. Plumacher, United States consul at Maracaibo, Venezuela, October 19, 1904, after 13 years and 4 months of life in the bird house, died on February 22, 1918. A male cassowary died October 21, 1917, of aspergillosis; it had been in the collection, in excellent health, for eight years. Others of the more serious losses were a wombat, a Japanese bear, the sable antelope, an eland, and a Cape Barren goose.

Through cooperation with the Department of Agriculture, post-mortem examinations were made, as usual, by the pathological division of the Bureau of Animal Industry.¹

Of the animals lost by death, all specimens of scientific importance or needed for museum work, 19 mammals, 20 birds, and 16 reptiles, were transferred to the United States National Museum for study and permanent preservation.

ANIMALS IN THE COLLECTION JUNE 30, 1918.

MAMMALS.

MARSUPIALIA.		Dusky phalanger (<i>Trichosurus fuliginosus</i>) --	
Virginia opossum (<i>Didelphis virginiana</i>).....	6	Brush tailed rock kangaroo (<i>Petrogale penicillata</i>).....	3
Tasmanian devil (<i>Sarcophilus harrisii</i>).....	2	Great gray kangaroo (<i>Macropus giganteus</i>).....	2
Phalanger (<i>Trichosurus vulpecula</i>).....	3	Red kangaroo (<i>Macropus rufus</i>).....	8

¹ The following list shows the results of autopsies, the cases being arranged by groups.

CAUSES OF DEATH.

Mammals.—Marsupialia: Pneumonia, 2; gastroenteritis, 1; peritonitis, 1. Carnivora: Pneumonia, 4; tuberculosis, 1; gastroenteritis, 2; enteritis, 1; septicemia, 1; cystic chondroma on head, 1. Pinnipedia: Gastroenteritis, 2. Rodentia: Pneumonia, 1; tuberculosis, 1; gastroenteritis, 4; severe constipation, 1. Artiodactyla: Pneumonia, 3; tuberculosis, 2; gastroenteritis, 2; pyæmia, 1. Perissodactyla: Tuberculosis, 1.

Birds.—Ratitæ: Aspergillosis, 1. Ciconiiformes: Digestive disorder, 1; enteritis, 1; impaction of crop, 1. Anseriformes: Tuberculosis, 3; aspergillosis, 3; enteritis, 8; catarrhal gastritis, 1; pericarditis, 1; avian gout, 1; anemia, 2; internal hemorrhage, 1; no cause found, 4. Falconiformes: No cause found, 1. Galliformes: Tuberculosis, 2; enteritis, 3; coccidial enteritis, 1; peritonitis, 1; no cause found, 4. Gruiformes: Exposure, 1; no cause found, 3. Charadriiformes: Enteritis, 5; ulcerative enteritis, 4; caseous tumor in peritoneal cavity, 1; no cause found, 1. Cuculiformes: Enteritis, 1; no cause found, 2. Coraciiformes: Hepatic hematoma, 1; septicemia, 4. Passeriformes: Enteritis, 1; inflammation of mucosa of duodenum, 1; anemia, 1; no cause found, 5.

Reptiles.—Serpentes: Parasitism, 1.

Kangaroo Island kangaroo (<i>Macropus melanops</i>)	2
Wallaroo (<i>Macropus robustus</i>)	3
Black-tailed wallaby (<i>Macropus ualabatus</i>)	1
Rufous-bellied wallaby (<i>Macropus billardieri</i>)	3
Parma wallaby (<i>Macropus parma</i>)	1
Nail-tailed wallaby (<i>Onychogale frenata</i>)	1
Wombat (<i>Phascolomys mitchelli</i>)	1

CARNIVORA.

Kadlak bear (<i>Ursus middendorffi</i>)	1
Alaska Peninsula bear (<i>Ursus gyas</i>)	2
Yakutat bear (<i>Ursus dalli</i>)	1
Kiddler's bear (<i>Ursus kielder</i>)	2
European bear (<i>Ursus arctos</i>)	4
Grizzly bear (<i>Ursus horribilis</i>)	3
Himalayan bear (<i>Ursus tibetanus</i>)	1
Black bear (<i>Ursus americanus</i>)	3
Kenai black bear (<i>Ursus americanus perniger</i>)	1
Cinnamon bear (<i>Ursus americanus cinnamonum</i>)	2
Glacier bear (<i>Ursus emmonsii</i>)	1
Sloth bear (<i>Melursus ursinus</i>)	1
Polar bear (<i>Thalarcos maritimus</i>)	2
Dingo (<i>Canis dingo</i>)	1
Eskimo dog (<i>Canis familiaris</i>)	2
Gray wolf (<i>Canis nubilus</i>)	10
Southern wolf (<i>Canis floridanus</i>)	1
Woodhouse's wolf (<i>Canis frustror</i>)	2
Coyote (<i>Canis latrans</i>)	3
Red fox (<i>Lulpes fulca</i>)	5
Gray fox (<i>Urocyon cinereogargenteus</i>)	1
Raccoon (<i>Procyon lotor</i>)	15
Gray coatiundi (<i>Nasua narica</i>)	1
Kinkajou (<i>Polos flavus</i>)	1
Ferret (<i>Mustela furo</i>)	1
Tayra (<i>Tayra barbara</i>)	1
Skunk (<i>Mephitis nigra</i>)	1
American badger (<i>Taxidea taxus</i>)	2
European badger (<i>Meles meles</i>)	2
Florida otter (<i>Lutra canadensis vaga</i>)	4
African civet (<i>Viverra civetta</i>)	1
Genet (<i>Genetta genetta</i>)	1
Spotted hyena (<i>Crocuta crocuta</i>)	1
Brown hyena (<i>Hyana brunnea</i>)	1
Striped hyena (<i>Hyana hyana</i>)	2
African cheetah (<i>Acinonyx jubatus</i>)	2
Lion (<i>Felis leo</i>)	4
Bengal tiger (<i>Felis tigris</i>)	1
Manchurian tiger (<i>Felis tigris longipilis</i>)	2
Leopard (<i>Felis pardus</i>)	2
East African leopard (<i>Felis pardus suahelica</i>)	1
Jaguar (<i>Felis onca</i>)	1
Mexican puma (<i>Felis azteca</i>)	2
Mountain lion (<i>Felis hippestes</i>)	3
Canada lynx (<i>Lynx canadensis</i>)	3
Bay lynx (<i>Lynx rufus</i>)	6
California lynx (<i>Lynx californicus</i>)	1

PINNIPEDIA.

California sea-lion (<i>Zalophus californianus</i>)	2
Harbor seal (<i>Phoca vitulina</i>)	1

RODENTIA.

Patagonian cavy (<i>Dolichotis patagonica</i>)	2
Peruvian guinea pig (<i>Cavia tschudii pallidior</i>)	5
Guinea pig (<i>Cavia porcellus</i>)	20
Coypu (<i>Myocastor coypus</i>)	2
Mexican agouti (<i>Dasyprocta mexicanana</i>)	1
Azara's agouti (<i>Dasyprocta azarae</i>)	2
Crested agouti (<i>Dasyprocta cristata</i>)	3
Paca (<i>Cuniculus paca</i>)	3
Visacha (<i>Lagostomus marinus</i>)	1
Crested porcupine (<i>Hystrix cristata</i>)	1
Woodchuck (<i>Marmota monax</i>)	1
Dusky marmot (<i>Marmota flaviventris obscura</i>)	1
Prairie-dog (<i>Cynomys ludovicianus</i>)	14
Albino squirrel (<i>Sciurus carolinensis</i>)	2
American beaver (<i>Castor canadensis</i>)	2

LAGOMORPHIA.

Domestic rabbit (<i>Oryctolagus cuniculus</i>)	15
--	----

EDENTATA.

Hairy armadillo (<i>Euphractus villosus</i>)	1
--	---

PRIMATES.

Black lemur (<i>Lemur macaco</i>)	1
White-throated capuchin (<i>Cebus capucinus</i>)	2
Margarita capuchin (<i>Cebus margarita</i>)	1
Chacma (<i>Papio porcarius</i>)	1
Hamadryas baboon (<i>Papio hamadryas</i>)	2
Mandrill (<i>Papio sphinx</i>)	1
Drill (<i>Papio leucophaeus</i>)	1
Moor macaque (<i>Cynopithecus maurus</i>)	1
Brown macaque (<i>Macaca speciosa</i>)	2
Japanese monkey (<i>Macaca fuscata</i>)	2
Pig-tailed monkey (<i>Macaca nemestrina</i>)	2
Rhesus monkey (<i>Macaca rhesus</i>)	20
Bonnet monkey (<i>Macaca sinica</i>)	1
Javan macaque (<i>Macaca mordax</i>)	1
Philippine macaque (<i>Macaca syrichta</i>)	1
Sooty mangabey (<i>Cercocebus fuliginosus</i>)	2

Green guenon (<i>Lasiopyga callitrichus</i>)	1
Vervet guenon (<i>Lasiopyga pygerythra</i>)	2
Mona (<i>Lasiopyga mona</i>)	3
Roloway guenon (<i>Lasiopyga roloway</i>)	1
Patas monkey (<i>Erythrocebus patas</i>)	3
Chimpanzee (<i>Pan troglodytes</i>)	1

ARTIODACTYLA.

Collared peccary (<i>Pecari angulatus</i>)	1
Wild boar (<i>Sus scrofa</i>)	1
Wart-hog (<i>Phacochoerus africanus</i>)	2
Hippopotamus (<i>Hippopotamus amphibius</i>)	3
Bactrian camel (<i>Camelus bactrianus</i>)	2
Arabian camel (<i>Camelus dromedarius</i>)	2
Guanaco (<i>Lama guanacoe</i>)	5
Llama (<i>Lama glama</i>)	9
Alpaca (<i>Lama pacos</i>)	2
Vicuña (<i>Lama vicugna</i>)	1
Fallow deer (<i>Dama dama</i>)	2
Axis deer (<i>Axis axis</i>)	6
Hog deer (<i>Mylaphus porcinus</i>)	7
Sambar (<i>Rusa unicolor</i>)	2
Luzon deer (<i>Rusa philippinus</i>)	1
Barasingha (<i>Rucervus duraoellii</i>)	12
Japanese deer (<i>Sika nippon</i>)	10
Red deer (<i>Cervus elaphus</i>)	16
Kashmir deer (<i>Cervus hanglu</i>)	4
Bedford deer (<i>Cervus xanthopygus</i>)	5
American elk (<i>Cervus canadensis</i>)	7
Virginia deer (<i>Odocoileus virginianus</i>)	11
Mule deer (<i>Odocoileus hemionus</i>)	4
Black-tailed deer (<i>Odocoileus columbianus</i>)	4

Blesbok (<i>Damaliscus albifrons</i>)	1
White-tailed gnu (<i>Connochaetes gnu</i>)	1
Oefassa water-buck (<i>Kobus defassa</i>)	1
Indian antelope (<i>Antilope cervicapra</i>)	6
Nilgai (<i>Boselaphus tragocamelus</i>)	4
Congo harnesssed antelope (<i>Tragelaphus gratus</i>)	2
East African eland (<i>Taurotragus oryx livingstonii</i>)	2
Tahr (<i>Hemitragus jemlahicus</i>)	3
Aoudad (<i>Ammotragus leucurus</i>)	4
Rocky Mountain sheep (<i>Ovis canadensis</i>)	6
Arizona mountain sheep (<i>Ovis canadensis gaillardi</i>)	1
Barbados sheep (<i>Ovis aries</i>)	7
Zebu (<i>Bos indicus</i>)	1
Anoa (<i>Anoa depressicornis</i>)	1
Yak (<i>Poëphagus grunniens</i>)	5
American bison (<i>Bison bison</i>)	18

PERISSODACTYLA.

Brazilian tapir (<i>Tapirus terrestris</i>)	3
Mongolian horse (<i>Equus przewalskii</i>)	1
Grant's zebra (<i>Equus burchelli granti</i>)	1
Grevy's zebra (<i>Equus grevyi</i>)	2
Zebra-horse hybrid (<i>Equus grevyi-e caballus</i>)	1
Zebra-ass hybrid (<i>Equus grevyi-asinus</i>)	1

PROBOSCIDEA.

Abyssinian elephant (<i>Loxodonta africana aegyptis</i>)	1
--	---

BIRDS.

South African ostrich (<i>Struthio australis</i>)	4
Somaliand ostrich (<i>Struthio molybdophanes</i>)	1
Rhea (<i>Rhea americana</i>)	2
Emu (<i>Dromiculus novahollandiarum</i>)	2

CICONIFORMES.

American white pelican (<i>Pelecanus erythrorhynchos</i>)	9
European white pelican (<i>Pelecanus onocrotalus</i>)	2
Roseate pelican (<i>Pelecanus roseus</i>)	2
Australian pelican (<i>Pelecanus conspicillatus</i>)	2
Brown pelican (<i>Pelecanus occidentalis</i>)	3
Florida cormorant (<i>Phalacrocorax auritus floridanus</i>)	18

Great blue heron (<i>Ardea herodias</i>)	1
Snowy egret (<i>Egretta candidissima</i>)	2
Black-crowned night heron (<i>Nycticorax nycticorax naevius</i>)	20
Boutbill (<i>Cochlearius cochlearius</i>)	2
White stork (<i>Ciconia ciconia</i>)	3
Black stork (<i>Ciconia nigra</i>)	1
Straw-necked ibis (<i>Arphibis spinicollis</i>)	2
Sacred ibis (<i>Threskiornis arhiopicus</i>)	3
White ibis (<i>Guara alba</i>)	11
Scarlet ibis (<i>Guara rubra</i>)	2
Roseate spoonbill (<i>Ajaia ajaja</i>)	2
European flamingo (<i>Phoenicopterus roseus</i>)	1

ANSERIFORMES.

Black-necked screamer (<i>Chauna torquata</i>)	1
Mallard (<i>Anas platyrhynchos</i>)	17

CHARADRIIFORMES.

Great black-backed gull (<i>Larus marinus</i>)	1
Herring gull (<i>Larus argentatus</i>)	1
Laughing gull (<i>Larus atricilla</i>)	2
Australian crested pigeon (<i>Ocyphaps lophotes</i>)	5
Wonga-wonga pigeon (<i>Leucosarcia picata</i>)	10
Speckled pigeon (<i>Columba phaeonota</i>)	1
Snow pigeon (<i>Columba leuconota</i>)	2
White-crowned pigeon (<i>Patagienas leucocephala</i>)	1
Band-tailed pigeon (<i>Chloranas fasciata</i>)	4
Red-billed pigeon (<i>Chloranas flavirostris</i>)	3
White-winged dove (<i>Mcloptia asiatica</i>)	1
Mourning dove (<i>Zenaidura macroura</i>)	5
Zebra dove (<i>Geopelia striata</i>)	13
Cape masked dove (<i>Oena capensis</i>)	1
Inca dove (<i>Scardafella inca</i>)	3
Blue-headed quail dove (<i>Sturnanus cyanocephala</i>)	1
Ringed turtle dove (<i>Streptopelia risoria</i>)	12

CUCULIFORMES.

White-crested touraco (<i>Turacus erythaia</i>)	1
Grass paroquet (<i>Melospittacus undulatus</i>)	2
Black-tailed paroquet (<i>Polytelis melanura</i>)	1
Banded paroquet (<i>Palaeornis fasciata</i>)	1
Lesser vasa parrot (<i>Coracopsis nigra</i>)	1
Gray parrot (<i>Psittacus erithacus</i>)	2
Haitian paroquet (<i>Aratinga chloroptera</i>)	1
Blue-winged parrotlet (<i>Psittacula passerina</i>)	1
Cuban parrot (<i>Amazona leucocephala</i>)	3
Yellow-shouldered parrot (<i>Amazona barbadensis</i>)	1
Festive parrot (<i>Amazona festiva</i>)	1
White-fronted parrot (<i>Amazona albifrons</i>)	1
Orange-winged parrot (<i>Amazona amazonica</i>)	1
Santo Domingo parrot (<i>Amazona ventralis</i>)	2
Yellow-headed parrot (<i>Amazona ochrocephala</i>)	5
Yellow-naped parrot (<i>Amazona auropalliata</i>)	2
Double yellow-head parrot (<i>Amazona oratrix</i>)	7
Yellow-cheeked parrot (<i>Amazona autumnalis</i>)	1

Plain-colored parrot (<i>Amazona fari-nosa inornata</i>)	1
Quaker parrot (<i>Myiopsitta monachus</i>)	1
Thick-billed parrot (<i>Rhynchopsitta pachyrhyncha</i>)	2
Brazilian macaw (<i>Ara severa</i>)	1
Red-and-blue macaw (<i>Ara chloroptera</i>)	2
Red-and-blue-and-yellow macaw (<i>Ara macao</i>)	7
Blue-and-yellow macaw (<i>Ara ararauna</i>)	1
Sulphur-crested cockatoo (<i>Cacatoes galerita</i>)	2
Great red-crested cockatoo (<i>Cacatoes moluccensis</i>)	1
White cockatoo (<i>Cacatoes alba</i>)	3
Leadbeater's cockatoo (<i>Cacatoes leadbeateri</i>)	1
Bare-eyed cockatoo (<i>Cacatoes gymnopsis</i>)	3
Roseate cockatoo (<i>Cacatoes roseicapilla</i>)	12
Kea (<i>Nestor notabilis</i>)	6

CORACIIFORMES.

Giant kingfisher (<i>Dacelo gigas</i>)	2
Concave-casqued hornbill (<i>Dicoceros bicornis</i>)	1
Barred owl (<i>Strix varia</i>)	6
Screech owl (<i>Otus asio</i>)	3
Great horned owl (<i>Bubo virginianus</i>)	2
Western horned owl (<i>Bubo virginianus pallaseus</i>)	1

PASSERIFORMES.

Red billed hill tit (<i>Liothrix luteus</i>)	7
Australian gray jumper (<i>Struthidea cinerea</i>)	1
Green jay (<i>Xanthoura lunosa</i>)	7
Australian crow (<i>Corvus coronoides</i>)	1
European raven (<i>Corvus corax</i>)	1
Malabar starling (<i>Spodiopsar malabaricus</i>)	1
Napolean weaver (<i>Pyromelana afra</i>)	2
Crimson-crowned weaver (<i>Pyromelana flammiceps</i>)	1
Madagascar weaver (<i>Foudia madagascariensis</i>)	4
Paradise weaver (<i>Steganura paradisea</i>)	2
Cut-throat finch (<i>Amadina fasciata</i>)	1
Zebra finch (<i>Taniopygia castanotis</i>)	7
Black-faced Gouldian finch (<i>Poephila gouldii</i>)	6
Red-faced Gouldian finch (<i>Poephila mirabilis</i>)	3
Strawberry finch (<i>Amandara amandava</i>)	12
Black-headed finch (<i>Munia atricapilla</i>)	4
Nutmeg finch (<i>Munia punctularia</i>)	13
Java finch (<i>Munia oryzivora</i>)	11

White Java finch (<i>Munia oryzivora</i>)	4	Saffron finch (<i>Sicalis flaveola</i>)	9
Vera Cruz red-wing (<i>Agelaius phoeniceus richmondi</i>)	2	Canary (<i>Serinus canarius</i>)	3
Song sparrow (<i>Melospiza melodia</i>)	3	Green singing finch (<i>Serinus icterus</i>)	2
Tree sparrow (<i>Spizella monticola</i>)	1	European chaffinch (<i>Fringilla caelebs</i>)	4
White-throated sparrow (<i>Zonotrichia albicollis</i>)	1	Red-crested cardinal (<i>Paroaria cucullata</i>)	2
		Cardinal (<i>Cardinalis cardinalis</i>)	1

REPTILES.

Crocodile (<i>Crocodylus acutus</i>)	1	Water snake (<i>Natrix sipedon</i>)	2
Alligator (<i>Alligator mississippiensis</i>)	31	Coach-whip snake (<i>Coluber flagellum</i>)	1
Mona Island iguana (<i>Cyclura stejnegeri</i>)	1	Chicken snake (<i>Elaphe quadrivittata</i>)	2
Gila monster (<i>Heloderma suspectum</i>)	6	Slug-eating snake (<i>Petalognathus nebulatus</i>)	1
Blue-tongued lizard (<i>Tiliqua scincoides</i>)	1	Duncan Island tortoise (<i>Testudo ephippium</i>)	1
Rock python (<i>Python molurus</i>)	3	Albemarle Island tortoise (<i>Testudo vicina</i>)	1
Diamond python (<i>Python spilotes</i>)	1		
Anaconda (<i>Eunectes murinus</i>)	2		
Bon constrictor (<i>Constrictor constrictor</i>)	4		

STATEMENT OF THE COLLECTION.

ACCESSIONS DURING THE YEAR.

Presented:		Transferred from other Government departments:	
Mammals	14	Mammals	8
Birds	50	Birds	2
Reptiles	39		10
	103	Captured in National Zoological Park:	
Born and hatched in the National Zoological Park:		Mammals	3
Mammals	63	Birds	5
Birds	45	Reptiles	1
	108		9
Received in exchange:		Deposited:	
Mammals	11	Mammals	3
Birds	25	Birds	6
Reptiles	6	Reptiles	9
	42		18
Purchased:		Total accessions	408
Mammals	13		
Birds	104		
Reptiles	1		
	118		

SUMMARY.

Animals on hand July 1, 1917	1,223
Accessions during the year	408
	1,631
Deduct loss (by exchange, death, and return of animals on deposit)	384
Animals on hand June 30, 1918	1,247

Class.	Species.	Individuals.
Mammals.....	149	483
Birds.....	190	706
Reptiles.....	15	58
Total.....	354	1,247

VISITORS.

All records for the numbers of visitors to the park have been exceeded during the past year. The total number of people admitted to the grounds, as determined by count and estimate, was 1,593,227, a daily average of 4,365. The greatest number in any one month was 202,793 in March, 1918, an average per day of 6,542. The attendance by months was as follows:

In 1917: July, 76,100; August, 157,700; September, 195,350; October, 175,350; November, 158,600; December, 70,350. In 1918: January, 35,850; February, 56,300; March, 202,793; April, 139,934; May, 187,300; June, 137,600.

These numbers exceed the attendance records for last year by 486,427, and are 436,117 over the attendance for 1916—the record year up to that time. Heretofore there has usually been a falling off in the number of visitors during the heat of summer; but, with the population of Washington so increased by war workers, the attendance throughout the past heated season has hardly diminished from that of spring and autumn.

The great increase in the number of visitors to the park in the past three years is graphically shown in the following statement of attendance records for the last 10 years:

1909.....	561,639
1910.....	721,555
1911.....	521,440
1912.....	542,738
1913.....	633,526
1914.....	733,277
1915.....	794,530
1916.....	1,157,110
1917.....	1,106,800
1918.....	1,593,227

Seventy-eight schools and classes visited the park in 1918, with a total of 4,945 individuals.

IMPROVEMENTS.

Owing to a lack of sufficient funds for any substantial improvements, only minor repairs or additions were made during the year to the buildings and equipment of the park. New boiler tubes and some other fittings in the central heating plant were provided at a

cost of about \$800. The restaurant building was repaired, the kitchen enlarged, and new counters provided. The old slippery and badly worn pavement was removed from the large elephant house and was replaced with a floor of concrete. The old and smaller elephant house was fitted up for winter quarters for certain of the waterfowl. Much-needed repairs were made to the lion-house roof, the western half of the north extension and the adjoining portion of the main roof were covered with new paroid-felt roofing, and a ventilator was placed in the main building over the public space. Minor repairs were also made to the bird house, the antelope house, and the Henderson outdoor parrot cage.

A large concrete bathing pool was constructed in the yak's inclosure and the tanks in the bear yards were all repaired. The fences of the bear yards, antelope yards, and some others of the outdoor cages and inclosures were painted. An outdoor cage 16 feet square, with shelter attached, was constructed for the kea parrots received as a gift from the New Zealand Government. The indoor chimpanzee quarters, in the lion house, were reconstructed with gratings of three-fourths inch iron pipe, which provide a much better hold for the animal's hands and feet than did the old three-eighths inch bars. Concrete walls and bases for shelter houses were built at some of the deer paddocks, the cinder footpaths were extensively repaired, and a concrete walk and stairway was built leading up the west hill side from the suspension bridge and connecting with the walk around the eland yards. Part of the stable building near the office was rebuilt for a chicken house and, in a further effort to lessen the cost of food for animals, the garden acreage was again materially increased.

THE FLORA OF THE PARK.

In addition to an extensive native flora, the park contains many exotic trees and shrubs. It is important that records be kept of all introductions. During the past year Mr. William Hunter, gardener, who has been in the service since the inception of the park, has prepared an annotated list of all the trees and shrubs found growing within the boundary fence. The list has been copied on cards for filing, and will be carefully edited and revised during the present season. Information is given as to the abundance and location of native species and, in the case of exotics, the source, date of introduction, location, or any additional information likely to be needed for future reference. Efforts will be made to secure specimens of trees properly belonging to the flora of the District of Columbia and not represented in the park, in order that all the native species may be found within this reserve. A similar list of herbaceous plants, prepared several years ago, will be brought up

to date, thus furnishing a complete catalogue of the flora of the park, which, it is to be hoped, may later be published in some form as part of a guide to the natural features of the park. Lists of the native mammals, birds, and reptiles of the park, with pertinent data, are also in preparation for some similar purpose.

ALTERATION OF THE WESTERN BOUNDARY.

By an act approved June 23, 1913, Congress appropriated \$107,200 for the purchase of certain lots and parcels of land between the western boundary of the National Zoological Park and Connecticut Avenue, from Cathedral Avenue to Klinge Road, this land, together with the included highways, to become a part of the park. The appropriation was not a continuing one and lapsed at the end of one year, before legal proceedings for the purchase were completed. Items for the reappropriation of this sum and for the additional amount necessary to meet the figures fixed by the court in proceedings of condemnation have since been submitted to Congress in the estimates each year, but have not been favorably considered.

The principal entrance to the park will always be from Connecticut Avenue, and the importance of a frontage on that thoroughfare at and bordering the gate can not be overestimated. The necessary land should be acquired before it is too late, in order that when the time comes a dignified entrance gate can be constructed and the nearby land controlled by the park authorities.

IMPORTANT NEEDS.

Roads, bridle paths, and automobile parking.—As mentioned in the report for last year, the question of providing space for the parking of automobiles near the main buildings is serious. The enormous increase in the number of cars visiting the park makes it difficult to care for the safety of the public without adequate parking space. More than 4,500 automobiles sometimes pass through the park in a single day, and many of the large sight-seeing cars regularly visit the Zoo. During the coming year it will be necessary to make extensive repairs to roads and walks, and some change should be made in the bridle path in order that riders would not be forced to use the bridge and main road from the Harvard Street gate to the crossroads.

Grading and filling.—As soon as practicable the work of grading and filling, commenced two years ago but discontinued for lack of funds, should be completed. As left, it makes an unsightly and unfinished-looking place in one of the most conspicuous points in the park bordering the main road. The further cutting away of the irregular hill in the center of the western part of the park and the filling in of the near-by ravine will level nearly 70,000 square

feet of ground which is now of little use and make available a further 25,000 square feet of ground at the ravine. This will eliminate a dangerous curve in the automobile road.

Repairs to antelope house.—Practically the whole west side of the antelope house needs reconstruction. The building is over 20 years old and the timbers and other woodwork on the west side are almost beyond repair. When the work is undertaken the walls should be fixed properly with concrete and the cages considerably enlarged. It is estimated that an expenditure of about \$2,000 will be necessary to put this building in good condition.

Adams Mill Road grade and stairway.—The work of grading Adams Mill Road between Clydesdale Place and Harvard Street, recently commenced by the District, will make necessary some expenditure on the part of the park to care for the resulting fill above the stairway and walk leading into the park from the Adams Mill Road gates. At present it is impossible to estimate the exact amount of work that will be needed, but it is probable that a new bridge and walk will have to be built at one point, with a substantial retaining wall at the base of the fill for the safety of the public. A very narrow strip of land between Adams Mill Road and the park, from Clydesdale Place to Ontario Road, still in private ownership, should be added to the park for the protection of this point.

Additional lake for waterfowl.—Exhibits of waterfowl are among the most popular and instructive features of the park. An additional lake, to be used for the birds in summer and for skating in winter, could be built at comparatively small expense on the open flat near the Harvard Street entrance.

Aviary building.—The need of a new house for the exhibition of birds has been felt for some years and is becoming more pressing because of the greatly increased numbers of visitors now cared for in the park. Such a building should be provided with commodious public space. The aisles in the old bird house are far too narrow for the crowds of the present day, and the exhibition of birds, important and valuable as it is, can not be properly displayed.

Reptile house.—A public exhibition building, properly constructed and equipped for the display of reptiles and amphibians, would be greatly appreciated by visitors. The small collection of reptiles now kept in inadequate and wholly unsuited quarters in the lion house is very popular. The reptile house should be planned to show in natural environment the various types of reptiles of economic importance, those sought and used for food, and those feared by man in many countries. The educational value of such a building could be developed to a point of great importance.

Outdoor quarters for mammals.—Many species of mammals, especially some of the larger carnivores, now kept in cages in heated

buildings, could be much better shown and more pleasantly and healthfully located in outdoor quarters with warm but unheated shelters. A large African lion, kept in the park for two winters without artificial heat, has shown marked improvement from such treatment. Such provision should be made for the exhibition of certain of the lions, the Siberian tigers, and other mammals. Outdoor cages, adjoining the winter quarters, should be constructed on the east side of the lion house for the leopards, jaguars, and hyenas. The unsightly row of cages along the crest of the hill north of the bird house should be replaced by new sanitary yards with comfortable but unheated retiring quarters attached.

Owing to the great increase in the number of people who take advantage of the recreational and educational features of the park, the necessity for a substantial increase in the appropriation for regular maintenance expenses is apparent. For the safety and comfort of the public the number of policemen, attendants, keepers, and caretakers must be augmented, as the force now maintained is not greater than was considered necessary when the attendance was barely half its present figures.

Respectfully submitted.

N. HOLLISTER, *Superintendent.*

DR. CHARLES D. WALCOTT,
Secretary Smithsonian Institution,
Washington, D. C.

APPENDIX 5.

REPORT ON THE ASTROPHYSICAL OBSERVATORY.

SIR: The Astrophysical Observatory was conducted under the following passage of the sundry civil act approved June 12, 1917:

Astrophysical Observatory: For maintenance of Astrophysical Observatory, under the direction of the Smithsonian Institution, including assistants, purchase of necessary books and periodicals, apparatus, making necessary observations in high altitudes, repairs and alterations of buildings, and miscellaneous expenses, \$13,000.

For observation of the total eclipse of the sun of June eighth, nineteen hundred and eighteen, including purchase of necessary apparatus and supplies, transportation of equipment to and from observing station, hire of temporary assistance, transportation and subsistence of observers, and miscellaneous expenses, \$2,000.

The observatory occupies a number of frame structures within an inclosure of about 16,000 square feet south of the Smithsonian Administration Building at Washington, and also a cement observing station and frame cottage for observers on a plot of 10,000 square feet, leased from the Carnegie Solar Observatory on Mount Wilson, Cal.

Its equipment comprises special optical, electrical, and other apparatus adapted to measure radiation of the sun, the sky, and terrestrial sources. Much of the apparatus has been built at the observatory instrument shop on the Smithsonian grounds in Washington according to designs of the director. The instrument maker, Mr. A. Kramer, has been employed by the observatory nearly 30 years in this experimental construction work, and his experience and skill, added to his natural ability, render him invaluable. New designs are continually being worked out as new experiments are being made.

The present value of the buildings and equipment is estimated at \$50,000. This estimate contemplates the cost required to replace the outfit for the purposes of the investigations. Owing to the highly specialized character of the apparatus no such value could be obtained at public sale.

WORK OF THE YEAR.

At Washington.—As heretofore the work of measuring and computing from the records obtained in the field on Mount Wilson has

gone on steadily in charge of Mr. F. E. Fowle, aided by Miss F. A. Graves, computer, and Mr. R. Eisinger, messenger.

Mr. Fowle completed and published¹ his investigation of the absorption of long wave rays by long columns of air containing known quantities of water-vapor. His results give the relations between absorption and atmospheric humidity, wave-length by wave-length, from the visible spectrum down to waves of more than 20 times the maximum visible wave-length, and for quantities of water ranging from $\frac{1}{200}$ to three times that which prevails in the vertical thickness of the atmosphere above Washington in clear spring weather. Many difficulties which were met required tedious subsidiary investigations which are described in the paper.

Notwithstanding the greatness of this contribution to meteorological science the subject of the relations of water-vapor and terrestrial radiation demands yet more investigation adapted to cover the range of wave-lengths from 16 microns to 50 microns, where Mr. Fowle was forced to give over the investigation temporarily, because no substance suitable to make a prism for forming the spectrum of these rays was known.

Mr. Aldrich has since investigated at the observatory a great number of natural crystalline and other substances, including many pure chemical preparations. None was found appreciably more transparent than rock salt, which was used by Mr. Fowle, except potassium iodide. Apparently this substance, if it could be procured in large crystals, or fused into a noncrystalline structure, would be suitable to carry the work to much longer wave-lengths. Efforts have been made, as yet unsuccessfully, to procure blocks of this substance of suitable proportions and inner structure for making large prisms.

Mr. Aldrich has carried on a number of investigations on the absorption and reflection of atmospheric-water-vapor, liquid water, lampblack, gelatin, and other substances to rays emitted by a blackened reservoir filled with boiling water. In these experiments he has employed rock salt transmission plates to roughly separate the total radiation into two parts, whose wave-lengths are respectively greater and less than about 20 microns, where rock salt ceases to be transparent. The results on water-vapor agree well with what Mr. Fowle's spectrum work would tend to indicate. They also show that an atmospheric layer about 50 meters deep, containing water-vapor equal to 0.05 centimeters of precipitable water, would probably absorb all the rays sent out by the 100° C. radiator which are non-transmissible to rock salt, that is above the wave-length 20 microns. This is in harmony with observations of the sun and of nocturnal radiation made by Mr. Aldrich on Mount Wilson, to which reference

¹ Water Vapor Transparency to Low-temperature Radiation. *Smiths. Misc. Coll.*, Vol. 68, No. 8, 1917.

will be made below. The results on liquid water show it to be completely opaque in layers of 1 centimeter or more thickness to all rays of the above described 100° C. radiation. The reflecting power of water surfaces to these rays varies with the angle of incidence as follows:

Incidence -----	0°	30°	55°	63°	70°	72°
Reflection o/o-----	2	3	7	10	17	22

From this it follows that though perfectly opaque in layers exceeding 1 cm. thickness, water is not a perfect absorber or a perfect radiator for long-wave rays. It may be regarded as emitting about 90 per cent as much radiation as the perfect radiator at temperatures from 0° to 100° C.

Lampblack paint proved partially transparent and partially reflecting. Further experiments are required before publishing definite results, but evidently those who employ lampblackened surfaces in experiments with long-wave rays should consider these imperfections of radiating and absorbing power.

An investigation was made on possible regularities of periodicity in the short-interval variability of the sun¹ observed at our Mount Wilson station. Dr. H. H. Clayton had made such an investigation for the year 1913 and found indistinct tendencies toward a repetition of "solar constant" conditions after intervals of 12 and 22 days. Computations were made here to extend the investigation to the other years from 1908 to 1916, excepting 1912.

Well marked relatively hot and cold hemispheres of the sun seem to have prevailed for several months in 1915, giving a "solar constant" periodicity of about 27 days. In 1916 an extraordinary regular periodicity of 3½ days seemed to be indicated. In other years tendencies to periodicities of other intervals were found, and generally more marked than in 1913, but not as prominently seen as in 1915 and 1916. On the whole the irregularity of period of the fluctuations of solar radiation would seem to be the most outstanding result of the inquiry.

In accordance with the wish expressed by Secretary Walcott, the facilities of the observatory have been employed whenever possible to assist in military investigations. This is not the time to detail the results of this effort further than to say that a large part of the work of the director and of Mr. Aldrich has been devoted to several such investigations, and with highly appreciated results. Naturally this has diminished the astrophysical output of the observatory.

Chilean expedition.—Preparations and arrangements for a South American solar-radiation expedition occupied much of the time of the director and that of the instrument maker. As stated in last

¹ On Periodicity in Solar Variation. Smiths. Misc. Coll., Vol. 69, No. 6, 1918.

year's report, a proposed expedition under the auspices of the Hodgkins fund to observe the solar radiation in the most cloudless region of Chile was temporarily postponed on account of the entry of the United States into war, and the expedition was diverted for a time to Hump Mountain in western North Carolina. Observations of the solar constant of radiation were made there, when weather permitted, until March, 1918. By that time it had grown to be certain that the site was too cloudy for the work, and, notwithstanding grave difficulties brought about by the war, the expedition was sent to Chile as originally proposed.

Director A. F. Moore and Assistant L. H. Abbot landed at Antofagasta, Chile, on June 16, 1918, with a large equipment of apparatus and supplies suitable to the investigation. They were greatly aided by the governor of the Province, the United States consul, and others, and the Chile Exploration Co. generously gave them the use of buildings and other valuable facilities at their disused mine at Chorillos, near Calama. Calama is a station on the railroad east of the nitrate desert, on the bank of the River Loa, at latitude N. $22^{\circ} 28'$, longitude W. $68^{\circ} 56'$, altitude 2,250 meters. Manuscript of daily meteorological records of two years, most kindly copied by Dr. Walter Knoche, former director of the Chilean Meteorological Service, lead us to hope for as many as 300 days per year favorable to solar-constant work there. The experiments are to be continued daily, as far as possible, for several years. They should furnish meteorologists with a firm basis for estimating the effects of the solar variability on the terrestrial climate.

TOTAL SOLAR ECLIPSE.

Owing to the pressure of military investigations our preparations for observing the total solar eclipse of June 8, 1918, were not extensive. The observations proposed were confined to observing the eclipse phenomena visually, photographing the solar corona, and determining the sun and sky radiation during the partial phase, and the "nocturnal" radiation during the total phase by means of the pyranometer.

Necessary apparatus was prepared at the observatory shop. It comprised parts for two 11-foot focus cameras, each of 3 inches aperture with equatorial mounting and driving clockwork, and two pyranometers. The observations were in charge of Mr. L. B. Aldrich, who was assisted by Mr. A. Kramer and by Rev. Clarence Woodman, a volunteer observer who had aided us in 1900.

The station selected was near Lakin, Kans., not because it was the most favorable, but because the more favorable parts of the eclipse track farther west would be occupied, it was known, by many eclipse parties, so that the chances of having clear weather at some station

were materially increased by the choice of one so far east as Kansas. Magnetic observers sent out by Dr. Bauer were also at Lakin, and, being already on the ground, aided materially in establishing Mr. Aldrich's party.

The observers chose the site on Monday, June 3, and were hospitably entertained at the home of Mr. Pittenger, a rancher. The cameras were set up in a barn looking out westward through a slot cut away for the purpose. Unfortunately cloudy and rainy weather hindered the preparations and prevented the rating of the clock and the photographic focusing of the lenses on the stars, so that the adjustment could be made but roughly.

On eclipse day, Saturday, June 8, no hope was felt of fair weather during the forenoon, but fortunately the sky became nearly free from clouds about 1 o'clock and continued so until after nightfall and during Sunday. All times of contact were observed by Rev. Fr. Woodman, who also exposed the cameras, as follows:

Latitude	37° 53' 04.2'' N.
Longitude	101 17 51.3 W.
Contacts (Greenwich mean time):	

	<i>H.</i>	<i>m.</i>	<i>s.</i>
First.....	10	19	48.5
Second.....	11	27	15.1
Third.....	11	28	37.3
Fourth.....	12	29	45.4

The observers regarded the eclipse as unexpectedly dark and the phenomenon as more than usually grand.

Very good photographs of the corona were obtained, showing extensions to about 3 diameters of the sun in some directions. Owing to lack of opportunity to rate the clock there was some evidence of imperfect following. The negatives were developed, with the kind permission and advice of Director E. C. Pickering, by Mr. King at Harvard College Observatory.

Messrs. Aldrich and Kramer observed successfully throughout the afternoons and early night hours of June 8 and June 9 with the pyranometer. The results obtained measure the gradual diminution of the radiation of the sun and of the brightness of the sky as the eclipse progressed, the outgoing radiation from the earth's surface during totality, the gradual increase of sun and sky radiation afterwards, their decline toward sunset, and the outgoing radiation from the earth's surface after nightfall. Numerical values will be published later.

WORK AT MOUNT WILSON.

Mr. L. B. Aldrich occupied the Mount Wilson station until October 11, 1917, and again after June 14, 1918. He continued the usual solar constant determinations and the determinations of the distribution of radiation over the sun's disk. Two improvements were introduced in the apparatus.

The coelostat used in solar constant work was provided with stellite mirrors in place of silver on glass, so that now the optical train of the spectrobolometer for solar constant work contains exclusively nontarnishable mirrors. This allows us to compare as never before the distribution of radiation in the solar spectrum from day to day. We hope now to determine surely whether the variations of solar radiations are uniform over the whole spectrum or predominate in certain wave lengths.

A specially designed vacuum bolometer like the one employed at Hump Mountain and in Chile and wholly sealed in glass so as not ever to require attention to renew the vacuum has been substituted. This bolometer was constructed to exact specifications as to length, breadth, and thickness of strips in accordance with completely worked-out unpublished theory of the bolometer. We are sure that it is the last word on the subject as regards adaptability to our investigation. All expected results are obtained in its actual use.

The sky was more cloudy than usual on Mount Wilson both in 1917 and 1918, during the time of our expeditions. In the winter, in November, December, and January of 1917-18, the Carnegie Institution observers reported unusually good weather for the season.

Mr. Aldrich carried on in 1917 some investigations to determine whether long-wave rays, not transmissible by rock salt (that is, exceeding 20 microns in wave length), occur in the solar beam at the earth's surface. The experiments indicated that they do not. He also investigated the transmissibility of the atmosphere for rays of more than 20 microns in wave length by means of the pyranometer with and without a rock-salt cover. The experiments showed that even toward the zenith these rays are wholly cut off by the lower layers of the atmosphere. Hence we may conclude from both the solar and nocturnal observations that our atmosphere is opaque to rays exceeding 20 microns in wave length, such as are emitted in recognizable quantities by bodies at terrestrial or solar temperatures. This result is in harmony with Mr. Aldrich's laboratory experiments above mentioned.

In June, 1918, experiments were begun at Mount Wilson to determine the distribution of solar radiation along that diameter of the solar image which is at right angles to the east and west diameter investigated in our usual tower telescope work. A special apparatus was arranged to slowly rotate the second mirror of the coelostat, and thus produce a regular drift of the solar image along any desired diameter. Preliminary results obtained show that the differences, if any, between the distribution of radiation along different solar diameters do not amount to 1 per cent.

PERSONNEL.

R. Eisinger resigned from our service in June, 1918, and after service in the Treasury Department enlisted in the Army.

SUMMARY.

During the year covered by this report, great advance has been made in the study of very long wave-length rays and their transmissibility in our atmosphere. Solar constant work at Mount Wilson has been continued and improved. An expedition under the auspices of the Hodgkins Fund of the Smithsonian Institution, but equipped and directed from the Astrophysical Observatory, has observed the solar constant at Hump Mountain, N. C., and now is located for a term of years in exceptionally favorable circumstances at Calama, Chile. The total solar eclipse of June 8, 1918, was successfully observed. The variability of the sun is shown to have vestiges of periodicity, though predominantly irregular. A great deal of attention has been given to war problems.

Respectfully submitted.

C. G. ABBOT,

Director Astrophysical Observatory.

Dr. C. D. WALCOTT,

Secretary Smithsonian Institution.

APPENDIX 6.

REPORT ON THE LIBRARY.

SIR: I have the honor to submit the following report on the activities of the library of the Smithsonian Institution during the fiscal year ended June 30, 1918:

Conditions abroad have curtailed exchanges to a great extent. Notwithstanding, a large number of foreign publications are being received regularly and the sets on file are up to date. Special attention has been given to exchanges with South American countries, with very gratifying results, and the same can be said of the domestic exchanges.

There were received during the year 27,212 packages, an increase of 2,920 over the year preceding. Of these, 26,230 were received by mail and 928 through the international exchanges. Correspondence connected therewith amounted to 1,087 letters and 2,725 acknowledgments on the regular printed forms.

SMITHSONIAN LIBRARY.

Main library.—Publications for the Smithsonian Main Library, after entry on the records, are forwarded to the Smithsonian deposit in the Library of Congress. During the fiscal year 2,773 were accessioned, consisting of 2,369 complete volumes, 419 parts of volumes, 954 pamphlets, and 88 charts. The accessions numbers were extended from 527,151 to 529,924.

The cataloguing included 3,331 volumes, 95 charts, and the addition of 1,334 new titles; 1,925 volumes were recatalogued; 1,050 cards were typewritten, and 4,086 printed cards from the Library of Congress, for publications deposited by the Institution, were filed in the catalogue. In accordance with the established policy, the public documents presented to the Smithsonian Institution, numbering 3,442, were transferred to the Library of Congress without stamping or recording.

Dissertations were received from the Universities of Pennsylvania, Johns Hopkins, Königsberg, Toulouse, Lund, and Breslau, and the technical schools of Dresden and Berlin.

The securing of exchanges in return for Smithsonian publications and missing parts to complete sets has been continued. Two hundred and twenty want cards for series in the Smithsonian Division at the Library of Congress were considered, and 168 volumes and 389 parts

of volumes were secured. Ninety-eight wants were completed. Action on the 85 want cards received from the periodical division resulted in the securing of eight volumes and 240 parts of volumes. The order division obtained, in response to 19 cards, 19 volumes and 18 parts of volumes. The total number of wants completed was 142.

Office reference library.—The accessions for the office library, which includes the Astrophysical Observatory and the National Zoological Park, amounted to 555 publications, distributed as follows: Office library, 278 volumes and 164 pamphlets; Astrophysical Observatory, 58 volumes and 49 pamphlets and parts of volumes; National Zoological Park, 91 volumes and 1 pamphlet.

Aeronautical library.—The importance and value of books relating to aeronautics has been manifested through their use by the student who has returned day after day to follow up a subject. There have been added during the year 128 volumes. The bibliography of aeronautics, which I have had in preparation for the National Advisory Committee for Aeronautics, has been completed and, with the close of the year, it is ready for the printer. The appropriation for printing was approved just at the close of the year.

Reading room.—The frequent use of the reading room is especially worthy of note. There were in circulation 3,520 periodicals, an increase of 153 over the year preceding.

During the summer months the use of the library was extended to the soldiers who drill each day on the Mall. Adequate facilities for letter writing were provided, and the room has been filled with soldiers daily during their rest periods.

Employees' library.—The number of volumes circulated in the employees' library has increased to 336. There has been practically no addition to the number of volumes, as the greater portion of the reading wants of employees can be supplied through the reading room and the war library of the Museum.

NATIONAL MUSEUM LIBRARY.

There has been one exceptional and important addition to the library of the United States National Museum, and that is a part of the botanical and horticultural publications brought together by the late Mr. George W. Vanderbilt on his estate at Biltmore, N. C. This collection formed the working library of the Biltmore Herbarium and was presented by Mrs. Vanderbilt. In 1916 the building on the Biltmore estate was inundated by a local flood which destroyed the larger part of the library, but fortunately many valuable volumes were saved. Some of these are distinct editions of works not heretofore available.

The museum received by transfer a collection of pharmaceutical works from the hygienic laboratory, May 15, 1918. This collection,

brought together by Dr. M. G. Motter, the librarian, consists of 932 volumes, 12 pamphlets, and 2,060 periodicals.

The continued interest of Dr. William H. Dall in books for the sectional library of the division of mollusks has resulted in the further enriching of this collection by gift from him of 237 titles during the year. Other contributions to the library were received from Dr. Charles D. Walcott, Dr. O. P. Hay, Dr. C. W. Richmond, Dr. W. H. Holmes, Mr. W. R. Maxon, Dr. G. C. Maynard, Mr. William Palmer, Mr. J. M. Flint, Mr. G. S. Miller, jr., Mr. B. H. Swales, Dr. Aleš Hrdlička, Mr. J. P. McLean, and Mr. R. C. Paine.

Accessions.—There were accessioned during the year 3,230 volumes, including 1,010 completed volumes of periodicals, 42 parts of volumes, and 1,529 pamphlets. The number of books in the library is now 137,008, consisting of 52,513 volumes, 124 manuscripts, and 84,371 pamphlets.

Cataloguing.—The cataloguing covered 1,436 volumes, 48 parts of volumes, and 1,938 pamphlets. Four thousand four hundred and twenty section cards were made.

Loans.—Eleven thousand two hundred and thirty-seven books were loaned during the year, of which 2,658 were borrowed from the Library of Congress and 122 from other libraries. The number of books consulted in the reading room is estimated at 6,110.

Binding.—With the additions to the library from the Library of the Biltmore Herbarium and the collection of works from the Hygienic Laboratory, the binding needs have become more acute, but everything is being done to relieve the situation in so far as the funds will allow. One thousand seven hundred and six books were sent to the Government binder during the year, and 841 have been returned.

Technological series.—Additions to the Technological Library, exclusive of duplicates, numbered 281 volumes, 3,863 parts of volumes, 454 pamphlets, and 4 maps. Periodicals entered on records and shelved number 35 volumes and 2,663 parts of volumes. Two hundred and thirty-one cards for books catalogued were filed in the library's catalogue. In the scientific depository catalogue 1,880 author cards were filed and, to 3,762 additional cards, subject headings were added and filed, making a total addition to the catalogue of 5,642 cards.

Duplicates received number 28 volumes, 278 parts of volumes, and 105 pamphlets. These were arranged and filed with the collection of duplicates.

The books and periodicals loaned during the year number 225 volumes and 157 parts of volumes and pamphlets, making a total circulation of 382; 142 completed volumes of periodicals were sent to and returned from the bindery during the year.

Biltmore Herbarium.—Of the collection of 2,000 volumes of works on botanical subjects, 404 titles and 37 files of periodicals have been checked and made ready for cataloguing and entry. Fifty of these volumes had not been represented before in any Washington library. They were accordingly catalogued in detail and it is expected that cards will be printed for them by the Library of Congress.

Pharmaceutical series.—The collection received by transfer from the Hygienic Laboratory numbered 932 volumes and 12 pamphlets. For these, 194 accession cards and 160 catalogue cards were made. There were catalogued 78 volumes and 5 pamphlets. Two thousand and sixty periodicals were entered and 324 cards written.

Sectional libraries.—Sectional libraries have been created for the registrar's office and for the war library and the Division of Wood Technology. Following is a complete list of sectional libraries:

Administration.	Mesozoic fossils.
Administrative assistant's office.	Mineral technology.
Anthropology.	Minerals.
Biology.	Mollusks.
Botany.	Oriental archeology.
Comparative anatomy.	Paleobotany.
Editor's office.	Parasites.
Ethnology.	Photography.
Fishes.	Physical anthropology.
Food.	Prehistoric archeology.
Geology.	Property clerk.
Graphic arts.	Registrar's office.
History.	Reptiles and batrachians.
Insects.	Superintendent's office.
Invertebrate paleontology.	Taxidermy.
Mammals.	Textiles.
Marine invertebrates.	Vertebrate paleontology.
Materia medica.	War library.
Mechanical technology	Wood technology.

BUREAU OF AMERICAN ETHNOLOGY LIBRARY.

This library is administered under the direct care of the chief of the bureau, and a report of its operations will be found in the report of that bureau.

ASTROPHYSICAL OBSERVATORY LIBRARY.

The collection of reference works relating to astrophysics has been in constant use. Fifty-eight volumes, 6 parts of volumes, and 43 pamphlets were added during the year.

NATIONAL ZOOLOGICAL PARK LIBRARY.

The library of the National Zoological Park is not extensive, being a strictly working library. Ninety-one volumes were added during the fiscal year.

SUMMARY OF ACCESSIONS.

The accessions during the year, with the exception of the library of the Bureau of American Ethnology, may be summarized as follows:

To the Smithsonian deposit in the Library of Congress, including parts to complete sets-----	2, 773
To the Smithsonian office, Astrophysical Observatory, and National Zoological Park-----	641
To the United States National Museum-----	3, 230
Total-----	6, 644

Respectfully submitted.

PAUL BROCKETT,
Assistant Librarian.

Dr. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

APPENDIX 7.

REPORT ON THE INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE.

SIR: I have the honor to submit the following report on the operations of the United States Bureau of the International Catalogue of Scientific Literature for the fiscal year ending June 30, 1918.

The war in Europe, which has now lasted four years, is throwing ever-increasing difficulties in the way of satisfactorily carrying on the work of the International Catalogue. A number of the countries now engaged in hostilities are falling behind in their subscriptions and the Central Bureau and all of the regional bureaus are having difficulty in obtaining suitable aid to compile and publish the index. The Governments of the countries taking part in the enterprise obviously have prior claims on all services needed in carrying on the war and on this account the Catalogue work has fallen somewhat in arrears. However, it is gratifying to be able to state that approximately two-thirds of the normal number of volumes, which would have been published in time of peace, have been published since the war broke out.

When hostilities began in 1914 the tenth annual issue of the Catalogue had just been completed and in addition 10 volumes of the eleventh issue and one of the twelfth issue. Since the outbreak of war the eleventh and twelfth issues have been completed, together with the greater part of the thirteenth issue and part of the fourteenth issue, the actual figures being as follows:

	Volumes.
Eleventh issue.....	7
Twelfth issue.....	16
Thirteenth issue.....	14
Fourteenth issue.....	4
Total.....	41

The London Central Bureau of the Catalogue, whose duty it is to edit and publish the references sent in from the various regional bureaus, is dependent entirely for its support on the receipts derived from the subscribers to the Catalogue throughout the world, and as six of the regional bureaus, namely, Germany, Austria, Hungary, Poland, Belgium, and Russia, are in arrears to the extent of almost \$9,000 per annum, it will be necessary to obtain a subsidy from some

source to finance the fifteenth annual issue of the Catalogue as was done in 1916 when grants from the Royal Society of London and from the Carnegie Foundation of New York enabled the Central Bureau to make up the first deficit caused by the war and provided funds for the publication of the fourteenth annual issue.

It is felt that every effort should be made to continue the organization as it now stands in spite of present and temporary difficulties caused by the war, for even if the work is delayed and also to some extent incomplete it is obvious that it would be a much simpler and more satisfactory method to continue this great international undertaking until the war is over with the present organization than it would be to reorganize the work should it be allowed at any time to cease or fall too far in arrears. The task of indexing much of the literature being published in the countries mentioned above, whose regional bureaus have closed, has fallen on the London Central Bureau, and already 15,000 reference cards for the German literature of 1915 have been prepared there. Whether it will be possible when peace is restored to resume the former cordial cooperation with all of the now hostile countries is a matter open to serious question, but if this can not be done for some years to come the literature published in those countries could be indexed by the Central Bureau, as is evidenced by the fact that the Central Bureau has already put this plan into operation. These and other questions will, however, have to be finally decided by another international convention after the war.

As has been pointed out a number of times before, the International Convention in London in 1910 authorized a committee to take all necessary steps to obtain further assistance and cooperation from other similar organizations in the preparation of the Catalogue in order to prevent duplication of work. This would not only lead to economy of labor, but would provide scientific workers with a complete and uniform reference to the literature of all sciences. Much is yet to be done in order to completely carry out the intent of the convention, and it can not be too strongly urged that as soon as war conditions allow the complete activities of the Catalogue to be resumed every effort be made to obtain such cooperation.

Not only is it strongly advisable to consolidate and cooperate with the publishers of scientific bibliographies, but also to so broaden the scope of the Catalogue as to include many of the technical industries whose investigations and methods of production are so closely allied with the progress of research in pure science as to render it practically impossible to draw a line of demarcation between pure science and many of the applied sciences.

Many difficulties have arisen to interfere with the work of this Regional Bureau, not only in having the classification properly done,

but also in obtaining sufficient clerical assistance to carry on the regular routine.

This in addition to difficulties of forwarding manuscript to London on account of dangers from submarines has reduced somewhat the number of index cards normally issued, but the methods of work have been so readjusted as to meet requirements in spite of temporary chaotic conditions.

Very respectfully, yours,

LEONARD C. GUNNELL,
Assistant in Charge.

Dr. CHARLES D. WALCOTT,
Secretary Smithsonian Institution.

APPENDIX 8.

REPORT ON THE PUBLICATIONS.

SIR: I have the honor to submit the following report on the publications of the Smithsonian Institution and its branches during the year ending June 30, 1918:

The Institution proper published during the year 13 papers in the series of Miscellaneous Collections, 1 annual report, pamphlet copies of 27 papers from the general appendices of these reports, and 5 special publications. The Bureau of American Ethnology published 1 bulletin and 1 advance separate belonging to a report now in press. The United States National Museum issued 1 annual report, 1 volume of the proceedings, 39 separate papers forming parts of these and other volumes, and 5 bulletins.

The total number of copies of publications distributed by the Institution and its branches was 134,284, which includes 1,591 volumes and separate memoirs of Smithsonian Contributions to Knowledge, 26,412 volumes and separate pamphlets of Smithsonian Miscellaneous Collections, 19,815 volumes and separate pamphlets of Smithsonian Annual Reports, 75,300 volumes and separates of National Museum publications, 7,344 publications of the Bureau of American Ethnology, 2,929 special publications, 14 volumes of the Annals of the Astrophysical Observatory, 44 reports of the Harriman Alaska Expedition, and 676 reports of the American Historical Association.

SMITHSONIAN MISCELLANEOUS COLLECTIONS.

Of the Miscellaneous Collections, volume 66, the title-page and table of contents was published; volume 67, 1 paper; volume 68, 7 papers; volume 69, 3 papers; in all, 11 papers, as follows:

VOLUME 66.

Title-page and table of contents. 5 pp. (Publ. 2478.)

VOLUME 67.

No. 3. Cambrian Geology and Paleontology. IV, No. 3. Fauna of the Mount Whyte formation. By Charles D. Walcott. May 9, 1917. 59 pp. (Publ. 2480.)

VOLUME 68.

No. 6. Meliaceae Centrali-Americanae et Panamenses. C. de Candolle. July 23, 1917. 8 pp. (Publ. 2479.)

No. 7. Descriptions of two new birds from Haiti. Charles W. Richmond. July 12, 1917. 3 pp. (Publ. 2481.)

- No. 8. Water-vapor transparency to low-temperature radiation. Frederick E. Fowle. October 27, 1917. 68 pp. (Publ. 2484.)
- No. 9. A new river dolphin from China. Gerrit S. Miller, jr. March 30, 1918. 12 pp. (Publ. 2486.)
- No. 10. New rodents from British East Africa. N. Hollister. January 16, 1918. 3 pp. (Publ. 2489.)
- No. 11. The Marine Algae and marine Spermatophytes of the Tomas Barrera Expedition to Cuba. Marshall A. Howe. April 9, 1918. 13 pp. (Publ. 2491.)
- No. 12. Exploration and field-work of the Smithsonian Institution in 1917. 134 pp. (Publ. 2492.)

VOLUME 69.

- No. 3. Atmospheric scattering of light. Frederick E. Fowle. May, 1918. 11 pp. (Publ. 2495.)
- No. 6. On periodicity in solar radiation. C. G. Abbot. January, 1918. 8 pp. (Publ. 2499.)
- No. 7. Report on aircraft supply of Great Britain and a discussion of the difficulty involved in production. June, 1918. 8 pp. (Publ. 2500.)

SMITHSONIAN ANNUAL REPORTS.

The completed volume of the Annual Report of the Board of Regents for 1916 was received from the Public Printer in December, 1917.

Annual Report of the Board of Regents of the Smithsonian Institution, showing operations, expenditures, and condition of the Institution for the year ending June 30, 1916. xii, 607 pp., 143 pls. (Publ. 2449.)

The general appendix contained the following papers, small editions of which were printed in pamphlet form:

- Administration and activities of the Smithsonian Institution. By A. Howard Clark. 19 pp. 22 pls. (Publ. 2450.)
- News from the stars. By C. G. Abbot. 12 pp. 5 pls. (Publ. 2451.)
- The distances of the heavenly bodies. By W. S. Eichelberger. 11 pp. (Publ. 2452.)
- A census of the sky. By R. A. Sampson. 12 pp. 6 pls. (Publ. 2453.)
- Gun-report noise. By Hiram P. Maxim. 6 pp. 7 pls. (Publ. 2454.)
- Molecular structure and life. By Amé Pictet. 13 pp. (Publ. 2455.)
- Ideals of chemical investigation. By Theodore W. Richards. 11 pp. (Publ. 2456.)
- The Earth: Its figure, dimensions, and the constitution of its interior. By T. C. Chamberlin, Harry Fielding Reid, John F. Hayford, and Frank Schfesinger. 30 pp. (Publ. 2457.)
- Dry land in geology. By Arthur P. Coleman. 18 pp. (Publ. 2458.)
- The petroleum resources of the United States. By Ralph Arnold. 15 pp. (Publ. 2459.)
- The outlook for iron. By James Furman Kemp. 21 pp. (Publ. 2460.)
- The origin of meteorites. By Fr. Berwerth. 10 pp. (Publ. 2461.)
- The present state of the problem of evolution. By M. Caullery. 15 pp. (Publ. 2462.)
- Some considerations on sight in birds. By J. C. Lewis. 9 pp. 5 pls. (Publ. 2463.)

- Pirates of the deep: Stories of the squid and octopus. By Paul Bartsch. 29 pp. 19 pls. (Publ. 2464.)
- The economic importance of the diatoms. By Albert Mann. 10 pp. 6 pls. (Publ. 2465.)
- Narcotic plants and stimulants of the ancient Americans. By W. E. Safford. 38 pp. 17 pls. (Publ. 2466.)
- New archeological lights on the origins of civilization in Europe. By Arthur Evans. 21 pp. (Publ. 2467.)
- The great dragon of Quirigua. By W. H. Holmes. 14 pp. 10 pls. (Publ. 2468.)
- A prehistoric Mesa Verde pueblo and its people. By J. W. Fewkes. 27 pp. 15 pls. (Publ. 2469.)
- The art of the great earthwork builders of Ohio. By Charles C. Willoughby. 12 pp. 13 pls. (Publ. 2470.)
- A half century of geographical progress. By J. Scott Keltie. 21 pp. 2 pls. (Publ. 2471.)
- The relation of pure science to industrial research. By J. J. Carty. 9 pp. (Publ. 2471.)
- Mine safety devices developed by the United States Bureau of Mines. By Van H. Manning. 12 pp. 7 pls. (Publ. 2472.)
- Natural waterways in the United States. By W. W. Harts. 34 pp. 9 pls. (Publ. 2473.)
- Theodore N. Gill. By William H. Dall. 8 pp. 1 pl. (Publ. 2474.)
- The life and work of Fabre, by E. L. Bouvier. 11 pp. (Publ. 2475.)

REPORT FOR 1917.

The report of the executive committee and proceedings of the Board of Regents of the Institution and report of the secretary, both forming part of the annual report of the Board of Regents to Congress, were issued in pamphlet form in December, 1917:

- Report of the executive committee and proceedings of the Board of Regents of the Smithsonian Institution for the year ending June 30, 1917. 17 pp. (Publ. 2488.)
- Report of the secretary of the Smithsonian Institution for the year ending June 30, 1917. 110 pp. (Publ. 2487.)

The general appendix of the report for 1917, which is now in press, contains the following papers:

- Projectiles containing explosives, by Commandant A. R.
- Gold and silver deposits in North and South America, by Waldemar Lindgren.
- The composition and structure of meteorites compared with that of terrestrial rocks, by George P. Merrill.
- Corals and the formation of coral reefs, by Thomas Wayland Vaughan.
- The correlation of the Quaternary deposits of the British Isles with those of the continent of Europe, by Charles E. P. Brooks.
- Floral aspects of the Hawaiian Islands, by A. S. Hitchcock.
- Natural history of Paradise Key and the near-by everglades of Florida, by W. E. Safford.
- Notes on the early history of the pecan in America, by Rodney H. True.
- The social, educational, and scientific value of botanic gardens, by John Merle Coulter.
- Bird rookeries of the Tortugas, by Paul Bartsch.

An economic consideration of orthoptera directly affecting man, by A. N. Caudell.

An outline of the relations of animals to their inland environments, by Charles C. Adams.

The National Zoological Park: A popular account of its collections, by N. Hollister.

Ojibway habitations and other structures, by David I. Bushnell, jr.

The sea as a conservator of wastes and a reservoir of food, by H. F. Moore.

National work at the British Museum—Museums and advancement of learning, by F. A. Bather.

Leonhard Fuchs, physician and botanist, by Felix Neumann.

In memoriam: Edgar Alexander Mearns, by Charles W. Richmond.

William Bullock Clark.

SPECIAL PUBLICATIONS.

The following special publications were issued in octavo form:

Publications of the Smithsonian Institution issued between January 1 and March 31, 1917. 1 p. (Publ. 2448.)

Publications of the Smithsonian Institution issued between January 1 and June 30, 1917. 1 p. (Publ. 2482.)

Publications of the Smithsonian Institution issued between January 1 and September 30, 1917. 1 p. (Publ. 2485.)

Publications of the Smithsonian Institution issued between January 1 and December 31, 1917. 3 pp. (Publ. 2490.)

Publications of the Smithsonian Institution issued between January 1 and March 31, 1918. 3 pp. (Publ. 2496.)

PUBLICATIONS OF THE UNITED STATES NATIONAL MUSEUM.

The publications of the National Museum are: (a) The annual report to Congress; (b) the Proceedings of the United States National Museum; and (c) the Bulletin of the United States National Museum, which includes the Contributions from the United States National Herbarium. The editorship of these publications is vested in Dr. Marcus Benjamin.

During the year the Museum published an annual report, one volume of the Proceedings, 39 separate papers forming parts of this and other volumes, and five bulletins.

The issues of the Proceedings were as follows: Volume 51 complete.

The issues of the Bulletin were as follows:

Bulletin 39. Parts A and D, Directions for collecting birds, and Directions for collecting, preparing, and preserving birds' eggs and nests.

Bulletin 67. Directions for collecting and preserving insects.

Bulletin 95. The fishes of the west coast of Peru, by Barton Warren Evermann.

Bulletin 97. The Grapsoid crabs of America, by Mary J. Rathbun.

Bulletin 101. The Columbian Institute for the promotion of arts and sciences.

A Washington society of 1816-1838, which established a museum and botanic garden under Government patronage, by Richard Rathbun.

Bulletin 102. Part 1, Coal products; Part 2, Fertilizers; Part 3, Sulphur; Part 4, Coal.

PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY.

The publications of the bureau are discussed in Appendix 2. The editorial work of the bureau is in charge of Mr. Stanley Searles, editor.

During the year one bulletin and one advance separate from the Thirty-third Annual Report were issued, as follows:

Bulletin 63. Analytical and Critical Bibliography of the Tribes of Tierra del Fuego and Adjacent Territory, by John M. Cooper. 233 pp. 1 pl.

Hawaiian Romance of Laleikawai, by Martha Warren Beckwith. An advance separate from the Thirty-third Annual Report. 384 pp. 5 pl.

There are at present four reports and seven bulletins in press.

REPORT OF THE AMERICAN HISTORICAL ASSOCIATION.

The annual reports of the American Historical Association are transmitted by the association to the Secretary of the Smithsonian Institution and are communicated to Congress under the provisions of the act of incorporation of the association.

The annual report for 1915 was published during the year, and the second volume of the 1914 report. The report for 1916 was in press at the close of the fiscal year.

REPORT OF THE NATIONAL SOCIETY OF THE DAUGHTERS OF THE AMERICAN REVOLUTION.

The manuscript of the Twentieth Annual Report of the National Society of the Daughters of the American Revolution for the year ending October 11, 1917, was communicated to Congress on June 4, 1918.

THE SMITHSONIAN ADVISORY COMMITTEE ON PRINTING AND PUBLICATION.

The editor has continued to serve as secretary of the Smithsonian advisory committee on printing and publication. This committee passes on all manuscripts offered for publication by the Institution or its branches, and considers forms of routine, blanks, and various other matters pertaining to printing and publication. Thirteen meetings were held during the year and 68 manuscripts were acted upon.

Respectfully submitted.

A. HOWARD CLARK, *Editor.*

DR. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDING JUNE 30, 1918.

To the Board of Regents of the Smithsonian Institution:

Your executive committee respectfully submits the following report in relation to the funds, receipts, and disbursements of the Institution, and a statement of the appropriations by Congress for the National Museum, the International Exchanges, the Bureau of American Ethnology, the National Zoological Park, the Astrophysical Observatory, the International Catalogue of Scientific Literature, etc., for the year ending June 30, 1918, together with balances of previous appropriations:

SMITHSONIAN INSTITUTION.

Condition of the fund July 1, 1918.

In addition to the total sum of \$1,000,000 deposited in the Treasury of the United States and authorized under section 5591, Revised Statutes, the details of which were given in our last report, there has accumulated from incomes, bequests, and by transfer the sum of \$60,024.38, which has been invested in bonds of approved character for the following specific accounts and carried on the books of the institution as the consolidated fund, viz:

Hodgkins general fund.....	\$37, 275. 00
Rhees fund.....	37. 00
Avery fund.....	10, 020. 38
Addison T. Reid fund.....	672. 00
Lucy T. and George W. Poore fund.....	1, 295. 00
George K. Sanford fund.....	74. 00
Smithson fund.....	651. 00
Chamberlain fund.....	10, 000. 00
Total.....	60, 024. 38

The guaranteed bonds of the West Shore Railroad Co., previously reported by your committee at their par value, have now been transferred to the consolidated fund with specific credit to the Hodgkins general fund at their market value.

One of the three pieces of real estate bequeathed to the Institution by the late Robert Stanton Avery has been sold, and the proceeds reinvested in bonds comprising the consolidated fund.

Statement of receipts and disbursements from July 1, 1917, to June 30, 1918.

RECEIPTS.

Cash on deposit and in safe July 1, 1917.....	\$9, 232. 56
Interest on fund in United States Treasury— \$60, 000. 00	
Other interest..... 3, 552. 02	
	<u>\$63, 552. 02</u>
Repayments, rentals, publications, etc.....	13, 503. 13
Contributions for specific purposes.....	24, 358. 87
Bills receivable.....	55, 000. 00
Proceeds from sale of real estate.....	8, 721. 00
	<u>165, 135. 02</u>
	174, 367. 58

DISBURSEMENTS.

Buildings, care and repairs.....	\$6, 216. 39
Furniture and fixtures.....	1, 395. 14
General expenses:	
Salaries.....	\$17, 572. 79
Meetings.....	20. 00
Stationery.....	646. 57
Postage, telegraph, and telephone.....	625. 29
Freight.....	24. 13
Incidentals, fuel, and lights.....	930. 00
Garage.....	2, 042. 64
	<u>21, 861. 42</u>
Library.....	2, 160. 86
Publications and their distribution:	
Miscellaneous Collections.....	2, 040. 69
Contributions to Knowledge.....	120. 00
Reports.....	46. 45
Special publications.....	186. 09
Publication supplies.....	185. 32
Salaries.....	6, 525. 37
	<u>9, 103. 92</u>
Explorations, researches, and collections.....	4, 229. 10
Hodgkins specific fund, researches, and publications.....	4, 836. 47
International Exchanges.....	614. 00
Gallery of Art.....	22. 52
Consolidated fund (invested).....	12, 725. 00
Bills receivable—time certificates.....	50, 000. 00
Interest accrued—consolidated fund.....	53. 78
United States third Liberty loan.....	10, 000. 00
Advances for field expenses, etc.....	49, 859. 08
	<u>173, 077. 68</u>
Deposited with Treasurer of the United States.....	1, 089. 90
Cash on hand.....	200. 00
	<u>1, 289. 90</u>
	174, 367. 58

The itemized report of the auditor confirms the foregoing statement of receipts and expenditures and is approved. A summary of the report follows:

CAPITAL AUDIT Co.,
METROPOLITAN BANK BUILDING,
Washington, D. C.

EXECUTIVE COMMITTEE, BOARD OF REGENTS, SMITHSONIAN INSTITUTION.

SIRS: We have examined the accounts and vouchers of the Smithsonian Institution for the fiscal year ended June 30, 1918, and certify the following to be a correct statement:

Total disbursements	\$173, 077. 68
Total receipts	165, 135. 02
Excess of disbursements over receipts	7, 942. 66
Amount from July 1, 1917	9, 232. 56
Balance on hand June 30, 1918	1, 289. 90
Balance as shown by Treasury statement as of June 30, 1917	5, 794. 38
Less outstanding checks	4, 806. 25
Balance	988. 13
Balance, American National Bank	101. 77
Cash on hand	200. 00
Balance June 30, 1918	1, 289. 90

The vouchers representing payments from the Smithsonian income during the year, each of which bears the approval of the secretary, or, in his absence, of the acting secretary, and a certificate that the materials and service charged were applied to the purposes of the Institution, have been examined in connection with the books of the Institution and agree with them.

CAPITAL AUDIT Co.,
By WILLIAM L. YAEGER, *President*.

All payments are made by check signed by the secretary on the Treasurer of the United States, and all revenues are deposited to the credit of the same account, except in some instances small deposits are now made in bank for convenience of collection.

The practice of investing temporarily idle funds in time deposits has proven highly satisfactory. During the year the interest derived from this source has amounted to \$1,275.

Your committee also presents the following summary of appropriations for the fiscal year 1918 intrusted by Congress to the care of the Smithsonian Institution, balances of previous appropriations at the beginning of the fiscal year, and amounts unexpended on June 30, 1918:

	Available after July 1, 1917.	Balance June 30, 1918.
International exchanges, 1916.....		
International exchanges, 1917.....	\$4,957.76	\$859.93
International exchanges, 1918.....	35,000.00	5,296.80
American Ethnology, 1916.....	334.97	¹ 314.87
American Ethnology, 1917.....	1,523.28	138.31
American Ethnology, 1918.....	42,000.00	3,817.51
International Catalogue, 1916.....	282.96	¹ 139.65
International Catalogue, 1917.....	466.00	226.77
International Catalogue, 1918.....	7,500.00	963.64
Astrophysical Observatory, 1916.....	38.06	¹ 38.06
Astrophysical Observatory, 1917.....	1,051.32	570.46
Astrophysical Observatory, 1918.....	13,000.00	1,771.14
Bookstacks for Government bureau libraries, 1915-16.....	62.12	¹ 62.12
Observations, eclipse of sun, 1918.....	2,000.00	1,929.88
National Museum:		
Furniture and fixtures, 1916.....	11.36	¹ 11.36
Furniture and fixtures, 1917.....	2,246.79	18.97
Furniture and fixtures, 1918.....	25,000.00	6,845.77
Heating and lighting, 1916.....	202.67	¹ 202.67
Heating and lighting, 1917.....	5,374.93	699.24
Heating and lighting, 1918.....	² 46,060.00	6,103.77
Preservation of collections, 1916.....	1,777.93	¹ 430.34
Preservation of collections, 1917.....	6,371.60	647.87
Preservation of collections, 1918.....	300,000.00	12,903.59
Books, 1916.....	235.31	¹ 159.48
Books, 1917.....	911.13	450.60
Books, 1918.....	2,000.00	1,227.60
Postage, 1918.....	500.00	
Building repairs, 1916.....	3.63	¹ 3.63
Building repairs, 1917.....	2,120.83	195.59
Building repairs, 1918.....	10,000.00	2,174.38
National Zoological Park, 1916.....	9.38	¹ 3.38
National Zoological Park, 1917.....	2,402.35	83.30
National Zoological Park, 1918.....	100,000.00	9,743.24
Increase of compensation, 1918.....	27,246.40	

¹ Carried to credit of surplus fund.² Supplemental appropriation, \$5,674.

Statement of estimated income from the Smithsonian fund and from other sources, accrued and prospective, to be available during the fiscal year ending June 30, 1919.

Balance, June 30, 1918.....	\$1,289.90
Bills receivable.....	\$20,000.00
Interest on fund deposited in United States Treasury due July 1, 1918, and Jan. 1, 1919.....	60,000.00
Interest from miscellaneous sources.....	3,422.10
Exchange repayments, sale of publications, refund of ad- vances, etc.....	31,653.71
Deposits for specific purposes.....	12,000.00
	<hr/> 127,075.81
Total available for year ending June 30, 1919.....	128,365.71

Respectfully submitted.

GEO. GRAY,
ALEXANDER GRAHAM BELL,
HENRY WHITE,
Executive Committee.

PROCEEDINGS OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE FISCAL YEAR ENDING JUNE 30, 1918.

ANNUAL MEETING DECEMBER 13, 1917.

The board met at the Institution at 10.15 a. m.

Present: The Hon. Edward D. White, Chief Justice of the United States, chancellor, in the chair; Senator Henry Cabot Lodge, Senator Henry F. Hollis, the Hon. E. W. Roberts, the Hon. George Gray, Mr. John B. Henderson, the Hon. Henry White, and the secretary, Dr. Charles D. Walcott.

APPOINTMENT OF REGENTS.

The secretary announced the following appointments of regents of the Institution: On March 4, 1917, the Hon. Thomas R. Marshall, Vice President of the United States, ex officio; on March 4, 1917, by the President of the Senate, the Hon. Henry Cabot Lodge, to succeed himself; on January 15, 1917, by joint resolution of Congress approved by the President, the Hon. Henry White, a citizen of Maryland, to succeed the Hon. Andrew D. White, resigned; on January 19, 1917, by joint resolution of Congress approved by the President, Mr. John B. Henderson, a citizen of Washington, D. C., to succeed himself at the expiration of his present term, on March 1, 1917.

RESOLUTION RELATIVE TO INCOME AND EXPENDITURE.

Mr. Roberts, of the executive committee, offered the following resolution, which was adopted:

Resolved, That the income of the Institution for the fiscal year ending June 30, 1919, be appropriated for the service of the Institution, to be expended by the secretary with the advice of the executive committee, with full discretion on the part of the secretary as to items.

ANNUAL REPORT OF THE EXECUTIVE COMMITTEE.

The secretary submitted the annual report of the executive committee, showing the financial condition of the Institution for the fiscal year ending June 30, 1917, stating that it had been supplied to the regents in printed form.

On motion, the report was adopted.

VACANCY IN EXECUTIVE COMMITTEE.

Mr. Roberts said that his term as a regent expired in a few days, and tendered his resignation as a member of the executive committee, which was accepted.

On motion, Mr. Henry White was elected to fill the vacancy thus created.

ANNUAL REPORT OF PERMANENT COMMITTEE.

Hodgkins fund.—In its last report, the committee gave a statement of the allotments and expenditures under a yearly grant of \$5,000 to the Langley Aerodynamical Laboratory for three years, showing the termination of this grant, with approved outstanding liabilities amounting to \$4,725.53. These liabilities included an allotment of \$2,000 for tests with the Langley machine and one of \$2,500 made to the United States Weather Bureau for investigations which would result in the mapping of the atmosphere up to 20,000 feet over the United States and adjoining area. Of these, the first has been paid and the second has been relinquished by the Weather Bureau as funds for this and other research have been provided by congressional action. There remains as liabilities, therefore, the small sum of \$225.53.

An allotment of \$5,000 per annum for three years was made to Dr. Charles G. Abbot, director of the Astrophysical Observatory of this Institution, for the establishment of an astrophysical station in the Argentine Republic. Owing to conditions brought about by the war, the location has been abandoned for the present, and the station has been established at Elk Park, N. C. Of the two allotments already made, \$6,261 have been expended.

No changes have occurred in the other bequests in which the Institution is interested, and which have been the subject of previous reports.

Freer Art Building.—The funds originally placed with the Institution by Mr. Charles L. Freer, of Detroit, for the construction of the building for his art collections, amounted to \$1,000,000 in cash and 2,000 shares of the capital stock of Parke, Davis & Co., of Detroit. At present the condition of the fund is as follows:

<i>Balance sheet.</i>	
Building fund (cash)_____	\$1,000,000.00
Stock (book value)_____	250,000.00
Interest and dividends_____	50,779.05
Construction_____	\$159,462.10
Architect's services_____	30,000.00
Architect's expenses_____	11,852.95
Sewer construction_____	1,500.00
Experimental gallery_____	5,526.02
Bills receivable (certificates of deposit)_____	810,000.00
Stocks_____	250,000.00
Cash_____	32,437.98
	<hr/>
	1,300,779.05 1,300,779.05

Smithsonian fund.—Your committee is pleased to report that the Smithsonian fund in the United States Treasury has reached the maximum sum authorized by law of \$1,000,000.

On motion, the permanent committee's report was accepted.

ANNUAL REPORT OF THE SECRETARY.

The secretary presented his report of the operations of the Institution for the year ending June 30, 1917, which was accepted.

THE SECRETARY'S SUPPLEMENTARY REPORT.

The secretary made the following statement in relation to recent operations in the various lines of the Institution's activities:

National Museum.—Attention is called to the necessity for increased appropriations for the Museum. Under heating and lighting a deficiency of \$5,824 has been requested for this year, due to the increased cost of coal—which is about 66 per cent greater than last year—and to the additional amount of coal required for properly heating and lighting the spaces occupied by the Bureau of War Risk Insurance. Under preservation of collections, Congress has been requested unsuccessfully to give sufficient funds not only for additional members of the staff for the department of arts and industries, but for some additional assistance in ethnology and biology. Particular stress, however, should be laid on the fact that the salaries for the watchmen, laborers, and certain classes of clerks and preparators are inadequate in view of the extremely high cost of living. The Museum is constantly losing members of its staff to the new bureaus of the Government where salaries are much larger, and also to private firms. It is urged that Congress take steps to increase the salaries of the watchmen and laborers, as well as to continue the 5 per cent and 10 per cent increases granted for the present fiscal year to employees receiving \$1,800 and less.

There are two notable historical acquisitions. One consists of a number of personal relics of Maj. Gen. George B. McClellan, United States Army, including swords, uniforms, and other military paraphernalia owned by him during the war with Mexico and the Civil War, presented to the Museum by his son, Maj. George B. McClellan, U. S. R. The second is the well-known Robert Hewitt Collection of Medallie Lincolnia, donated by Mrs. Robert Hewitt. This contains some 1,200 medallions, medals, tokens, and badges commemorating the life and services of President Lincoln, and is an exceptionally complete aggregation of medallie souvenirs of that President, dating from the period of the Civil War to the early part of the twentieth century.

In biology several hundred mammals and birds have been received from the Collins-Garner expedition in Africa, and by gift of Dr.

William L. Abbott important collections in anthropology and zoology have come from the Celebes, collected by his representative, Mr. H. C. Raven, and from Haiti, collected by Dr. Abbott personally.

In geology mention should be made of an almost complete skeleton of the unique fossil *Dimetrodon*, a carnivorous reptile distinguished for the extraordinary length of its spinal processes; one of the best-known crystal aggregate of cinnabar (mercury sulphide) from Hunan Province, China, as a gift from United States Consul Nelson T. Johnson, of Changsha; a meteoric stone from Eustis, Fla., of interest as being but the second find of meteoric stones within the State limits; besides some 16,000 specimens of invertebrate fossils from various sources.

Among the normal activities carried forward by the Division of Mineral Technology may be mentioned:

The practical completion of a large model showing occurrence and recovery of gold. A complete model of lead manufacture, costing \$7,500, received and being set up. Donation from the National Lead Co. A supplementary exhibit of lead, costing about \$3,000, planned for and promised by the National Lead Co. and others. A coal-tar products exhibit of products now being made in this country. This has been assembled.

Under special war emergency activities there have been published:

A résumé of the fertilizer situation in the country, and needs in the way of remedial action. A similar résumé for sulphur. The same for coal products, this latter being strictly an interpretation of the coal-products exhibit. A résumé, under preparation and nearly ready for the printer, on the fuel situation, including coal, oil, and hydroelectric power.

In further connection with the activities of this division, it may be mentioned that a tentative offer has been made by the fertilizer industry of \$30,000 to \$50,000 for use in the assembling of an exhibit for the museum in that field.

A recent paper by the assistant secretary, entitled "The Columbian Institute for the Promotion of Arts and Sciences," is of particular moment, since the museum of the institute was the nucleus of the United States National Museum, some objects in the latter being clearly traced to the earlier establishment. This is true of the uniform worn by Washington in resigning his commission.

National Gallery of Art.—The exhibition of a large collection of paintings, by Ossip Perelma, was continued from the preceding half year. The gallery is indebted to this artist for excellent portraits of Secretary Walcott, Mr. Frank B. Noyes, and Boris Bakhmeteff, the Russian ambassador. An excellent portrait of the American sculptress, Vinnie Ream (Vinnie Ream Hoxie), by G. A. P. Healy, was presented by Brig. Gen. Richard L. Hoxie.

In November a most interesting collection of 100 lithographs of war-work subjects in Great Britain and in the United States, by Joseph Pennell, was exhibited in the central room of the gallery, and attracted much attention. This exhibition was formally opened on the evening of November 1, by the Secretary of the Navy.

A number of important loans of art works have been recorded by the gallery.

Museum space taken up by the Bureau of War Risk Insurance.—Through inability to find appropriate quarters elsewhere in the city, the Bureau of War Risk Insurance, at the request of the President of the United States, was given headquarters on the ground floor of the new building of the National Museum—consisting of the foyer with adjoining rooms, two rooms on the south side of the east north range, and the whole clear space in the west north and west ranges between the laboratories and the north and west walls—in all, aggregating over 25,000 square feet. This area, part of which furnished space for meetings, special exhibitions, etc., and a passage to the auditorium from the north entrance of the building will, for a time, therefore, be closed to the public.

Urgent requests have been received for a great deal of additional space, and the correspondence on the subject was submitted for the information of the board. After a full discussion the following resolution was offered by Mr. Roberts and was adopted:

Resolved, That there shall be a committee of the board of regents on the use of the National Museum buildings by the departments of the Government, and the erection of structures on the Smithsonian grounds, which committee shall act for the board with full power on all matters comprehended by this resolution.

Resolved, That such committee shall be appointed by the chancellor, who shall be ex officio a member thereof.

The chancellor thereupon appointed the following committee:

The Hon. Henry White;
The chancellor (Chief Justice White);
Senator Lodge;
Senator Stone;
Representative Ferris;
Mr. Henderson.

The secretary will act as the secretary of the committee.

On motion of Mr. Roberts the board approved the action of the secretary in assigning to the Bureau of War Risk Insurance the amount of space mentioned.

Freer Gallery of Art.—Progress on the construction of the building for the Freer collections has proceeded as planned.

In this connection it may be remarked that at the last meeting the board was informed of the project to bring about the cancellation by Congress of the assessment of \$13,252.21 against Mr. Freer as an

income tax on profit on a sale of certain shares, \$1,000,000 of which had been presented to the Institution for the purpose of erecting a building to house his great gift of art objects. I am glad to report that the sundry civil act of June 12, 1917, carried a provision authorizing the cancellation.

The Springer collection.—For some years past office and exhibition space has been allotted to Dr. Frank Springer, a valued collaborator of the Museum, for his comprehensive and instructive collection of fossil crinoids and related groups of echinoderms. Recently Dr. Springer decided to give the Smithsonian Institution the title and custody of these collections in perpetuity. He has executed an indenture providing for this, reserving their use to himself during his lifetime, and arranging for a fund of \$30,000, the income of which is to be devoted solely to the administration of the collections under the specified conditions. The terms of the gift were placed before the permanent committee, which approved its acceptance.

On motion the board approved the action of the permanent committee in accepting the gift of Dr. Frank Springer on the terms as laid down in the indenture.

Bureau of American Ethnology.—Field researches of the Bureau of American Ethnology were continued in New Mexico, where important excavations were conducted in the ruins of the great pueblo of Hawikuh, and an archeological reconnaissance was made in western Colorado, which brought to light the remains of many interesting prehistoric tower-like structures of excellent masonry, many of which had not hitherto been known to science.

Ethnological investigations were continued among the remnants of various tribes in southern California which are on the verge of extinction; also among the Iroquois of Canada, the Fox Indians of Iowa, and the Chippewa of Minnesota.

National Zoological Park.—The readjustment of the western boundary, a matter of vital importance to the park, is still pending, efforts to have the necessary appropriation made at the last session of Congress having failed. The amount necessary for the purchase of the land to be taken, including the cost of the proceedings, is \$175,641.43. The matter is urgent, because the area of active improvement on Connecticut Avenue has reached the border of this land and is likely to extend in the near future. A marked increase in the number of visitors to the park has been noted. During the first four months of the present fiscal year the attendance was 604,500, an increase of 230,450 over the corresponding months of last year and greatly in excess of the figures for the same period in the record year. This is no doubt due to the great number of strangers and troops in the city.

Astrophysical Observatory.—Solar constant observations were conducted by the Astrophysical Observatory at Mount Wilson, Cal., during the past summer and autumn. Results were obtained showing that the earth's atmosphere is entirely opaque to rays of more than 20 microns in wave length and that all such rays were found cut off in a path of 12 feet in air. This is important to meteorology, because about one-fourth of the rays emitted by the earth's surface are above 20 microns wave length.

Expeditionary observations at Hump Mountain, N. C., under a grant from the Hodgkins fund are progressing and will be continued all winter. The work includes measures of the solar constant of radiation, measures of the brightness of the sky, measures of nocturnal radiation, and experiments bearing on frost prediction.

The Astrophysical Observatory is continuing the study of the transparency of the air to long-wave rays such as the earth sends out. The atmosphere on clear days appears to transmit only about 20 to 30 per cent of the earth's rays outward to space, the quantity transmitted decreasing as humidity increases.

The reduction of the Mount Wilson observations is nearly up to date. An investigation of the periodicity of solar radiation is under way and is about to yield interesting results. A periodicity attending the period of the sun's rotation is found in 1915 when there was much sun-spot activity.

A determination of the constant of the formula for total radiation is in progress.

Langley Aerodynamical Laboratory.—In the report of the secretary of the board at its meeting on December 11, 1916, a brief statement was made on the development that had taken place in connection with the Langley Aerodynamical Laboratory.

In this statement attention was called to an allotment of \$2,500 for the investigation of problems of the atmosphere in relation to aeronautics in cooperation with the United States Weather Bureau of the Department of Agriculture. Through the representations of the National Advisory Committee for Aeronautics, Congress appropriated \$100,000 for work in this important field by the Weather Bureau, and the \$2,500 allotted by the Institution have been credited back into the fund of the Langley Aerodynamical Laboratory.

The work of the National Advisory Committee for Aeronautics has enlarged rapidly during the past year. At its suggestion the Council of National Defense appointed a Committee on Aircraft Production, which was later reconstituted under an act of Congress the Aircraft Board, with power to consider all questions of aircraft production and to make recommendations to the military departments for the production and purchase of aircraft and aircraft appliances.

The experimental laboratory of the Advisory Committee is now in process of erection at Langley Field, near Hampton, Va. In the meantime experimental work is being conducted under the direction of the committee at several laboratories.

The original Langley man-carrying flying machine has been brought back from Hammondsport after its successful trials, and soon will be placed on exhibition in the old National Museum building. It is the first heavier-than-air, man-carrying machine ever built, although it did not have a successful flight until more than 10 years after its construction. It is also an important historical relic, as it confirms the claim that Secretary Langley was the first to design and construct a heavier-than-air machine capable of carrying a man in flight. There has never been any question that he was the first to successfully fly a heavier-than-air machine propelled by its own power.

Borneo and Celebes expedition.—Owing to the generosity of Dr. W. L. Abbott, a valued collaborator of the National Museum, an extensive expedition has been in operation in these islands for several years, under the leadership of Mr. H. C. Raven. Collecting is now being carried on in central Celebes, and the Museum has received a new lot of objects which is especially rich in ethnological material. Previous mention has been made of the results of this expedition and of the gifts of Dr. Abbott, who has contributed the sum of \$21,000 for this purpose since 1912.

Santo Domingo and Haiti expedition.—Dr. Abbott is now personally continuing his collections in Santo Domingo and Haiti, from which he has secured for the National Museum many interesting mammals and birds.

Biological work in North China.—Mr. A. de C. Sowerby is continuing his exploration work in northeastern China, and a small collection was received from him in May, 1917. His work has been attended with considerable difficulty, however, owing to the unsettled condition of the country. It will be remembered that this expedition is being financed by a friend of the Institution, who declines to allow his identity to become known.

Collins-Garner Congo expedition.—In November, 1916, Mr. A. M. Collins, of Philadelphia, asked the Museum to participate in an expedition to the French Congo which he was organizing in conjunction with Mr. R. L. Garner, Mr. Collins assuming the main financial burden of the expedition. It was arranged that the Smithsonian Institution should send a zoological collector, pay his salary and transportation, and in addition turn over \$1,200 to Mr. Collins, for which sum he agreed to give our representative the privileges of the expedition until the end of September, 1917. Mr. Garner and our

representative, Mr. C. R. W. Aschemeier, sailed about the middle of December, but were unable to reach the collecting grounds until March. They encountered many difficulties along the way, but these were finally overcome, so that serious work began in April. One shipment of material has already been received and another is on the way. Both mammals and birds from West Africa are of great importance to our collections for comparison with the East African material brought together by the Smithsonian African expedition and the Rainey expedition.

GENERAL APPENDIX

TO THE

SMITHSONIAN REPORT FOR 1918.

ADVERTISEMENT.

The object of the **GENERAL APPENDIX** to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution, from a very early date, to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and this purpose has, during the greater part of its history, been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880 the secretary, induced in part by the discontinuance of an annual summary of progress which for 30 years previous had been issued by well-known private publishing firms, had prepared by competent collaborators a series of abstracts, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report for 1918.

THE DISCOVERY OF HELIUM AND WHAT CAME OF IT.

By C. G. ABBOT,

Assistant Secretary, Smithsonian Institution.

This story is about a chemical element that was discovered in the sun, confirmed in the stars, recognized long after upon the earth, was instrumental in realizing the dreams of the alchemists, and finally found a useful place in the great war. It came upon our stage at the time of one of those wonderful natural phenomena called total solar eclipses.

About once every year the moon comes exactly between the sun and the earth, and as its apparent size is generally slightly greater than that of the sun, although in reality far smaller, it covers over the brilliant disk of the sun and allows us to see those objects which are so close to the sun in their apparent position as ordinarily to be obscured by the brilliant glare of the sky in the solar neighborhood.

On August 18, 1868, a very notable total solar eclipse was visible in India. Many astronomers journeyed there to observe it, among them the French astronomer, Janssen. It was only a few years before this that the spectroscope began to reveal the inmost nature of substances when these are heated sufficiently to give off light. Many astronomers employed the spectroscope at the Indian eclipse and all made substantially the same report. They found that the bright prominences which shot out to different heights about the sun's disk, and which had been seen in many previous eclipses, revealed spectra consisting of bright lines. Conspicuous among these lines were the lines of hydrogen, but other bright lines were seen in the prominence spectrum, among them one of yellow, which they mistook for the characteristic bright line of sodium. Their observations completely demonstrated the fact that the prominences are enormous masses of highly heated gaseous matter shot up to immense distances above the surface of the sun, and that of these gases hydrogen is among the most prominent. So far all were agreed, but Janssen went beyond this. The lines were so brilliant during the eclipse, as seen in his spectroscope, that he believed he could see them also in full sun-

light. Clouds prevented him from trying the experiment that afternoon, but the next morning he completed the necessary adjustments and drawing his spectroscope toward that portion of the sun's edge where the day before the most brilliant prominences had been seen during the eclipse, he found that the same lines came out again clear and distinct. Now he could study them at his leisure, not hurried by the quick rush of the eclipse phenomena, and he determined accurately the positions of the lines in the spectrum. He immediately confirmed his first conclusion that hydrogen is the most conspicuous of the prominence materials, but found that the yellow line which had been attributed to sodium was slightly displaced from the position of the real sodium lines and must probably be the revealed characteristic radiation of a new chemical element.

Messrs. Lockyer and Frankland confirmed the results of Janssen, and proved definitely that the yellow line could not be ascribed to the spectrum of any known terrestrial element. Frankland proposed for the new discovery the name of "helium," from the Greek "helios," the sun, and this name has been universally accepted for it.

After some years the yellow line of helium and some others which appeared to be associated with it were detected in the spectra of some of the stars. These lines are found as dark absorption lines in the spectra of the Orion stars, but bright in the spectra of certain others, and both bright and dark in the spectra of some of the so-called new stars.

Much searching was done to find this new element upon the earth, but, until 1895, without success. In that year Dr. Ramsay, a collaborator with Lord Rayleigh in the discovery of argon in the atmosphere, made an examination of the gas given off on digesting with acid specimens of Norwegian cleveite. He found in this spectrum the conspicuous yellow line of helium as theretofore known in the sun. Associated with helium he found also argon and other gases. Cleveite is a species of pitch-blende and is one of the ores of uranium. It was soon found that the gas helium was quite widely distributed upon the earth, though in minute quantities, and was found in other ores of uranium and also in the gases given off by certain mineral springs, even found free in the atmosphere in traces, and was also to be found associated with natural gas in the gas wells of the United States. It was also found in meteoric iron.

Of course the spectrum and all the properties of the new element were carefully studied, and it was found to be an inert chemical. Its molecule contains but one atom, whereas hydrogen and oxygen molecules have two. The greatest efforts have been made to cause it to combine with other chemical elements. Every device known to science has been employed, but without success. No combinations whatever can be made between helium and any other known chemi-

cal elements. This is a property which it shares with some of the other rare gases discovered about the same time—argon, neon, xenon, and others.

Readers will admit that up to this point the history of helium had been one of surprises. Found originally in the sun, 90,000,000 miles away; traced to the stars, thousands of times as far away as the sun; over a quarter of a century elapsed before it was found upon the earth, and when found, although a chemical element, it differed from almost all chemical elements in being wholly indifferent to all other constituents of the world. But the wonders of the story had hardly begun.

In 1898 the discovery of radium, another chemical element, surprised the world, for the properties of radium were found more strange than those of helium. Radium was found to be continually giving off portions of itself. It was found to be capable of fogging photographic plates through solid sheets of metal entirely opaque to light. It was found to be continually giving up heat, and some persons thought that here at last was a violation of the well-known second law of thermodynamics, which maintains that heat can not continually flow by a self-acting process from a cooler body to a warmer one. This paradox was later understood, for it was found that the shooting off of a part of itself by the radium made available those stores of inner chemical energy which could be continually converted into heat energy almost inexhaustibly in point of time. With the discovery of this extraordinary property of radium the mystery of the long existence of life upon the earth and the next corollary to it, the long existence of the sun as a source of radiation, became less puzzling. For although no sources of energy known up to that time had been suggested which were competent to maintain the sun's radiation for the hundreds of millions of years demanded by the geologist and the zoologist to account for the phenomena they study, yet if there be chemical elements which decompose their inmost atoms with a continual evolution of heat, here may be an almost unlimited source from which to draw for all demands of geology and biology, as far as they relate to the sun.

But what became of the particles shot off by radium? They were found to consist of gases, and some of these gases themselves were of short life and eventually split up into others. Two stable products of the decomposition of the atoms of radium and its immediate products were at length recognized. One of these is the well-known metal lead, the other is our friend helium. Not only does radium break up with the evolution of helium, but also uranium, thorium, and possibly also other chemical elements. Thus was explained the tendency of helium to be associated with uranium ores, for un-

doubtedly the uranium comprised in these ores is continually degenerating and forming the helium as it does so.

Thus the dreams of the old alchemists had almost come true. For centuries they had endeavored to transmute the chemical elements, thus to produce the precious metals, such as gold and silver. In this they had always failed. But nature, that more powerful alchemist, had now revealed its secret that the chemical elements are not immutable but may be transmuted one into the other. Unfortunately for commercial applications, no processes have ever been discovered by means of which the change of radium and its associates into helium and other metals can either be hurried or retarded. Nature retains full control of the apparatus. Hitherto man has been unable to usurp the government of it.

Among the properties of helium has been noted its chemical inertness. In other words, no combinations of helium with other chemical elements can be made. This means that helium can not be burned. We well know that hydrogen burns with tremendous energy in oxygen or in air, but nothing of the kind takes place with helium. By no process whatever can helium be burned. Another most interesting physical property of helium gas is the extreme difficulty of liquefying it. During the nineteenth century almost all of the so-called permanent gases were liquefied. Hydrogen resisted the attack the longest, but even hydrogen was at last liquefied and even solidified. Helium, however, resisted that degree of cold and pressure to which hydrogen had yielded itself as a liquid, and it was only in 1908 that Kamerlingh Onnes, the distinguished Dutch physicist, succeeded actually in liquefying helium. The temperature at which he arrived in this process was but 4° C. above absolute zero, that unique beginning of all motion of the molecules and of properties of many kinds. Measured on the absolute centigrade scale, the temperature of the sun is about $6,000^{\circ}$ to $7,000^{\circ}$; that of the earth about 285° ; freezing water, 273° ; liquid oxygen, 90° ; liquid hydrogen, 20° ; and liquid helium, 4° .

Onnes was able to reach almost to 2° absolute by employing helium in a special way, and employed this new extreme of cold to test the electrical and other properties of metals. Very extraordinary results were found. Tin, lead, and mercury (which is a solid, of course, at these temperatures) suddenly lost their properties of electrical resistance. Thus a thread of mercury that measured several hundred ohms at room temperatures, at $2^{\circ}45$ Abs. C. had so little electrical resistance that it could not be detected, and certainly less than 10,000,000,000 of what it had at the temperature of freezing water. Probably this curious sudden change of electrical behavior occurs with other metals, too.

Here, then, we have read two new chapters of the wonderful history of helium, its relation to the dreams of the alchemists, and its approach to the extreme limit of the realm of cold. The last chapter of the story deals with the great war.

For two decades previous to the invasion of Belgium the Germans had been constructing their Zeppelins, and the possibilities of this new war weapon were variously estimated. Their employment of it, however, to scatter destruction over undefended towns had not been dreamed of, and the horror which their earlier raids across the Channel into England roused will not soon be forgotten. However, this diabolical engine of destruction proved not to be invulnerable. The hydrogen gas with which these great ships were filled in order to make them lighter than air was in the highest degree inflammable, and when the airplanes reached their high degree of efficiency the aviators were able to destroy the Zeppelins by means of inflammatory bullets. Experiments made in the United States have shown that about one in four of the inflammatory projectiles which pierce a hydrogen filled balloon is apt to set it on fire. In this way the Germans lost several Zeppelins, and recognizing the danger of their employment and the comparatively meager results achieved, they at length discontinued the employment of them. But they continued their devilish raids by the use of airplanes, which had reached such large dimensions and such degrees of adaptability for maneuvering that long trips could be made with them to scatter death and destruction over civilian populations.

At length the Allies retaliated. They also sent their airplanes to give the Germans some realization of that kind of warfare. Their aerial fleets outnumbered the Germans, and with the entrance of the United States into the war probabilities of still further aerial attacks upon Germany became far stronger. But it occurred to allied officers that if a noninflammable gas could be used, then the Zeppelins themselves, which were far more capable of carrying great weights of guns and bombs, and were capable of making long flights into enemy territory, would be even more suitable for this kind of warfare. Ammonia and hot air were suggested and tested for such purposes, but owing to their comparatively considerable weight as compared with hydrogen they were not altogether satisfactory. But some enthusiast suggested that if helium, which is next lightest to hydrogen of all the gases, could be used the problem would be solved. Nothing apparently was more absurd. Kamerlingh Onnes had spent an enormous amount of time to collect for his experiments on liquefaction of helium so little as 2 cubic meters of gas. A terrible misfortune occurred to him, for an accidental leakage in his apparatus caused the loss of much of this precious store.

The cost of producing helium at the outbreak of the war was about \$1,600 per cubic foot, and Zeppelin balloons would require many hundreds of thousands of cubic feet. Apparently the suggestion was merely a wild dream absolutely incapable of realization. However, there are in Texas and Oklahoma certain gas wells which yield as much as nine-tenths of 1 per cent of helium. Plants were constructed to recover helium from the natural gas by means of liquefaction. As the temperature and pressure are properly adjusted and the temperature reduced, the natural gas first liquefies and runs away; after this the nitrogen and oxygen which may be present, and so on, one after another of the various gases of which the mixture is composed, until at length helium stands alone. In this way it was found possible to recover about 60 per cent of the helium in the mixture, so that a yield of about one-half per cent was obtained from the original natural gas. Of course, no waste of the natural gas itself for combustion occurred, for the liquefied gas could be warmed and could be quite as useful as before for purposes of combustion.

Several large plants were operated by the Government in Texas for the recovery of helium. The matter was, however, kept a well-guarded secret. Even the name was hidden. Photographs of the plant taken, were labeled "argon" manufacturies. The idea was spread that the purpose of the experiments was to produce a new variety of poisonous gas for warfare, or perhaps a special variety of gasoline for use in airplanes. All sorts of camouflage were adopted to prevent the enemy from learning the true purpose of the experiments. So far had the work progressed that at the time the armistice was signed a consignment of 150,000 cubic feet of helium was on the dock at New York, waiting to be sent to France to be used by the Allies for their balloons. Plans were on foot for increasing the output of helium enormously, so that it is probable that had the war lasted until the summer of 1919 the Allies could have employed helium gas for observation balloons and for Zeppelins with entire immunity from all possibility that they could be shot down with incendiary bullets.

It seems a far cry from the peaceful sun, 90,000,000 miles away, and the still more peaceful stars that dot the summer night, at more immeasurable distances, to the horrible war which has just been ended upon our little earth, but yet who knows when he goes about an investigation to increase the bounds of knowledge, however remote his subject may be from the ordinary walks of life, what applications the future may have in store for the results he gains?

AN ACCOUNT OF THE RISE OF NAVIGATION.¹

By R. H. CURTISS.

One of the most obvious practical benefits directly traceable to astronomical research is found in the application of celestial observations to the solution of the problems of navigation. Though other sciences have contributed their quota, it is mainly astronomy that has made the ocean safe for the navigator.

The fundamental problem of navigation is: Given the position on the earth of the port to be reached, to determine the ship's positions and the best courses to be steered at suitable intervals from the beginning to the consummation of the voyage. This problem, so important commercially, is, strictly speaking, one of science, for it depends chiefly for its accurate solution on the application of the principles and methods of practical astronomy.

For obvious reasons the accuracy attainable in determinations of position and direction at sea is much inferior to that possible on shore. The unsteadiness of the platform of a ship, the uncertainties of atmospheric refraction near or on the horizon, and the intervention of cloudy periods while the ship is progressing through disturbing currents and winds are formidable difficulties which the navigator must meet. But the results attainable with care leave only a small element of risk affecting modern transportation at sea.

Quite different was the position of the navigator in early times. The compass was introduced generally into Europe about 1400 A. D. Before this time the only practical means of navigating a ship on the Atlantic and Mediterranean was to keep in sight of land, or occasionally, for short distances, to direct the ship's course by reference to the sun and stars. But this latter rough method failed in cloudy weather, and even during short voyages on the Mediterranean in such circumstances the navigator became hopelessly bewildered as to his position. Frequently on the China Sea and the Indian Ocean vessels were able to traverse long distances out of sight of land by running directly before the steady winds, called the monsoons, which prevail in those localities. But the compass was an important

¹ Reprinted by permission from *Popular Astronomy*, Vol. XXVI, No. 254, April, 1918. The author expresses acknowledgements especially to the United States Hydrographic Office and the *Encyclopedia Britannica*, for material used in this article.

adjunct even there, and such methods of navigating were makeshifts at best.

The general adoption of the mariner's compass, about 1400 A. D., was followed by a period of progress in navigation, particularly among the Portuguese, whose exploring expeditions during the fifteenth century led to important discoveries in the Atlantic. Prior to this time the methods in use were very rude, uncertain, and dangerous. When a fleet of merchant vessels was sent to distant ports the trader was content if one or two returned and he fixed the prices on his precious imports accordingly.

But even at the beginning of the seventeenth century, navigation was still in a very backward state. That the compass needle does not point true north had been noticed early; that the amount of variation from north was different for different localities had been noted by Columbus or Cabot about 1490; but that the variation of the compass changes from year to year at the same base was not known until 1635.

At this time (about 1600) a navigator's equipment included a compass for directing the course; a rough weight and line for making soundings; a cross-staff or astrolabe for measuring angles; a fairly good table of the sun's distance north or south of the equator; and corrections for the altitude of the pole star. The last four appliances were used solely to determine the latitude or the distance on the earth's surface north or south of the terrestrial equator. Occasionally a very incorrect chart helped determine the ship's position. In this connection the motion of the ship was usually determined by estimating the speed every two hours or so, or, in some cases, by throwing out a float from the bows of the ship and noting the interval of time between its passage abeam of two observers standing on the deck at known distances apart.

By observations with the cross-staff and astrolabe on the sun or the pole star, latitude could be measured at sea with sufficient accuracy to fix the observer's position north or south of the equator within 20 miles or so, but no method was available for finding longitude or position east or west on the earth, except the rough expedient of estimating the run of the ship, taking wind, tide, and current into account. The only mode of arriving at a port of destination was to steer so as to get into the latitude of such a port either to the eastward or westward of its supposed position, and then to approach it on its parallel of latitude by steering a course due east or west. Obviously this method, though the best then available, might prove fatal if the error in longitude were too great.

The advice on longitude finding given by a nautical authority of repute at this time illustrates well the status of the problem up to the eighteenth century. He observes:

Now there be some that are very inquisitive to have a way to get the longitude, but that is too tedious for seamen, since it requireth the deep knowledge of astronomy, wherefore I would not have any man think that the longitude is to be found at sea by any instrument; so let no seamen trouble themselves with any such rule, but (according to their accustomed manner) let them keep a perfect account and reckoning of the way of their ship.

Such a record of the way of a ship appears to have been made with chalk on a wooden board called a log board which folded like a book and from which each day a position for the ship was deduced.

But while the longitude problem at sea remained unsolved, contributions to progress in navigation were being made in other directions. Mercator and Wright developed a correct sailing chart about 1600. Gunter's tables in 1620 made possible the application of logarithms to navigation. In 1631 a device, called the vernier, for accurate reading of scales became known. In 1635 Gellibrand published his discovery of the annual change in the variation of the compass needle. In 1637 Norwood helped remove one of the greatest stumbling blocks in the way of correct navigation by determining improved values of the length of a minute of arc on the earth's surface, or the true nautical mile. His value was about six-tenths of 1 per cent too large. In 1699 Halley constructed the first compass variation chart.

In the meantime some progress was being made with the longitude problem. It was recognized that the only accurate method of determining the longitude is by knowing the difference at the same instant between the time at the meridian of Greenwich and that of the observer. The determination of the local time for the observer by astronomical observations of the altitude of suitably situated heavenly bodies was an old, well-known and frequently practiced operation. But the simultaneous determination of Greenwich time presented great difficulties. Obviously if the ship were near enough to a station on the Greenwich meridian a rocket or a loud explosion could be used as a signal at some stated Greenwich time. The ship's time for the same instant could then be observed and the difference between these two times for the same instant would be the longitude of the ship east or west of Greenwich. But for ships out of signal range from Greenwich observations of celestial phenomena had to be employed. At present chronometers are carried on board ship which, after being corrected and rated at departure, keep accurate Greenwich time throughout the voyage and thus render longitude determination relatively easy. But chronometers of satisfactory accuracy were not available till late in the eighteenth century.

The best method known for determining Greenwich time at sea by observation before the chronometer became available was that, depending upon the measurement of the distance of the moon from

selected stars. For the moon makes a rapid circuit of the sky once each month and in so doing passes close to a number of bright stars. Hence if the navigator can be provided with tables giving the Greenwich time when the moon should be found to be distant from a given star by a given amount which he has measured, then the Greenwich time of the instant of that observation becomes known and may be kept by an hour glass or watch for a few minutes while the ship's time is being found.

This method for determining longitude was foreseen as early as 1514, but its practical application was attended with difficulties, not surmounted indeed before another and better method had been developed through the invention of the accurate chronometer. The difficulties in the way of the lunar distance determination of longitude were imperfect knowledge of the moon's motion and the crude character of the instruments for measuring angles, together with some inferiority inherent in the method.

The study of the longitude problem was stimulated by a prize of 1,000 crowns offered by Philip III of Spain, followed by another of 10,000 florins by the states-general for the discovery of a method of finding longitude at sea. As a result it was brought out that methods depending on the moon's position offered the best solution at that time, but that the lunar tables extant were useless, and that much study and observation would be necessary to make them available. Primarily to attack this lunar problem England established her national observatory in 1675. Fifty-six years later the astronomer royal in charge of the Greenwich Observatory announced that he hoped to be able to compute the moon's position within such limits that longitude errors would be reduced to 60 geographical miles at the equator. Apparently progress had been slow.

In 1714 England's commission for the discovery of longitude at sea had been constituted with power to grant large sums in prizes. For a method of determining the longitude within 60 geographical miles, to be tested by a voyage to the West Indies and back, £10,000 was offered; within 40 miles, £15,000; within 30 miles, £20,000.

The importance of further progress in methods of navigation at this time is brought out by accounts of actual casualties showing what the dangers were. Admiral Wheeler's squadron, in 1694, leaving the Mediterranean, ran on Gibraltar when it was thought the strait was safely passed. Sir Cloudesley Shovel's squadron, in 1707, was lost on the rocks off Scilly, by erring in the latitude. Several transports in 1711 were lost near the St. Lawrence River, having erred 45 miles in their reckoning. Lord Belhaven was lost on the *Lizard* in 1721, the same day on which he sailed from Plymouth, England.

At this point two most vital discoveries making for advancement in navigation were made. The rise of modern navigation may fairly be dated from the invention of the sextant by Hadley in 1731 and of the chronometer by Harrison in 1735. The sextant is an instrument for the measurement of angular distances. As such it replaced the cross-staff and the astrolabe, than which it is far more convenient and accurate. The cross-staff required the observer to sight in two directions at once, while the sextant forms two images of the object or objects observed as near together as desired in a small telescope. The astrolabe was suspended and was supposed to be kept plumb by gravity, but the movement of the ship rendered accuracy impossible. Three observers were required to manipulate it. The sextant is easily handled by one observer, who, with practise, soon acquires great proficiency and accuracy in the measurement of angles although his position may be on the unsteady deck of a ship at sea.

The chronometer is a timepiece like a watch in that it is actuated by a spring and depends upon a balance wheel for the measurement of time. It is however much larger and usually much more accurate than a watch, and it is mounted on gymbals so that it may by its own weight remain face up when its case is tipped.

In early times mariners used the compass as a rough sundial for the determination of time. Waterclocks and sandclocks were employed for rough purposes of keeping time on board ship, and it is curious to note that hour and half-hour sand glasses were used in the British navy until 1839. When watches were introduced in 1530 they were not accurate enough to supersede even the primitive devices then in use. The practical difficulty arose from their very irregular rates, owing to change in temperature and the motion of the ship. Harrison's great invention, which made possible the chronometer and greatly improved the watch, was the principle of compensating the balance wheel by the use of two metals with different coefficients of expansion, together with a device by which the chronometer retains its motion while being wound.

Harrison was eager to try for the longitude prizes with the help of his new invention. He believed that his timepiece, if set and rated carefully before embarking, could be relied upon to keep Greenwich time for a voyage of several months with such accuracy that greatly improved longitude determinations at sea could be effected. In 1735 he was allowed to test one of his first watches on a voyage to Lisbon, with a result so satisfactory that he received a grant of £500 to carry out further improvements. The official trial journey to the West Indies was begun in November, 1761, with an improved chronometer; and during the whole voyage of five months the total error unallowed-for was 1 min. 54.5 sec. or the equivalent of 18 geographical miles in

the latitude of Portsmouth, an amount well within the limit of 30 miles specified for the grand prize of the longitude commission.

Apparently Harrison had won the prize of nearly \$100,000.00; but the invention of the sextant, which had helped Harrison by facilitating the determination of local time, had been especially favorable to certain powerful competitors who hoped to gain the reward by measurement of lunar distances from stars. Much improved lunar tables had been submitted by Mayer in 1755. These were pronounced generally correct within a minute of arc; and Maskelyne, after a trial voyage to St. Helena in 1761, during which he determined longitudes within 90 miles or so, prepared a guide, issued in 1763, in which he asserted his belief that the lunar method would determine longitudes always within 60 geographical miles on the equator and generally within 30 miles, if applied to careful observations. Encouraged by this progress, though the process involved was too laborious for seamen to undertake, the House of Commons withheld the prize from Harrison and left an open chance for a lunarian during four years from 1763.

In March, 1764, on another trial voyage to the West Indies, Harrison's watch made a record even better than before, running four months with an error not greater than 10 geographical miles in longitude. Accordingly in the following year he was awarded one-half of the prize of £20,000; but at the same time, authority and funds were given for the publication of the Nautical Almanac, containing among other things tables of the moon's distance from the sun, when suitable, and from seven fixed stars at intervals of three hours. Apparently the longitude commissioners were still in doubt.

The tables of lunar distances in the Nautical Almanac, together with Maskelyne's auxiliary tables, facilitated greatly the lunar method for finding longitude. But steady progress toward the perfection of the chronometer maintained the superiority of the chronometer method of longitude determination, and soon after 1800 the longitude controversy may be considered to have been settled in favor of the accurate timepiece.

The marvelous accuracy of the modern chronometer—of even the cheaper chronometers used in the mercantile marine—is illustrated by the steamship *Orellana* sailing from London to Valparaiso. In a voyage of 63 days the mean accumulated error of her three chronometers was only 2.3 seconds of time, or six-tenths of a mile in longitude at the equator, and less in higher latitudes.

At the present time, since the Greenwich time can be sent out by wireless from shore stations, in the problem of longitude determination even less dependence need be placed on the chronometer, and the accuracy of such determinations is not necessarily appreciably different from that of latitudes.

Equipped with the compass and log, sextant, chronometer, lead, Nautical Almanac, and the Requisite Tables the navigator was ready to sail with comparative safety over long voyages early in the nineteenth century. The crying need was for more and better charts and for better knowledge of tides, winds, and currents. The establishment of the Admiralty Hydrographic Office of Great Britain in 1795 marked a great step in advance in these directions. The first official catalogue of the Admiralty, issued in 1830, listed 962 charts. And in 1832 official tide tables were issued also by the Admiralty. At present the navigator's charts cover all the important coasts and seas, with very full data of tides, winds, and currents.

In the United States, marine chart work began in the Navy Department in 1837. From 1844 to 1861 the United States Observatory and Hydrographic Office under Lieut. M. F. Maury devoted itself not only to astronomical and hydrographic work but also to important research in marine meteorology. This period is notable for the issuance of Maury's famous "Wind and Sailing Charts" and "Sailing Directions." It was Maury's wish that the wind and sailing charts should be an exclusively American contribution to world navigation. In 1866 the hydrographic and meteorological branches were disconnected from the Naval Observatory and given to the present Hydrographic Office, and in 1904 the work of marine meteorology was transferred to the Weather Bureau. The United States Hydrographic Office conducts marine surveys, collects information for nautical publications, and prepares manuals, charts, sailing directions, and nautical tables for the use of navigators generally. In a single year it prints about four hundred thousand charts and many more pamphlets and bulletins. It sells about one hundred thousand charts and books to navigators each year. The United States Coast and Geodetic Survey, as part of its activities, prepares and distributes tide tables and also charts and pilots of our coasts.

In recent times the great development of modern ships in both size and speed has increased enormously the demands on those who command and navigate them and has led to careful study and improvement of methods in navigation. Simplified procedure, better tables, and a higher standard of preparation of the navigator have been realized. On the instrumental side the sextant and chronometer have been carried toward perfection, the sounding machine much improved, and the gyro-compass introduced. The original model of one of the best modern types of magnetic compass was patented by Lord Kelvin in 1876. The gyro-compass is used side by side with the magnetic compass, but can not be said to have superseded it. The rotary or patent log came into general use about 1836, but was introduced in the form usually employed at present in 1878. It

records the revolutions of a small screw towed by the ship and, like a speedometer, registers the speed of the ship and the distance run at any instant.

The important features of modern practice in navigation may be brought out by a brief account of methods now employed. In planning out in advance a long ocean voyage the navigator would first lay down on a chart the track from port to port. For this purpose the monthly Pilot Chart, which is a Mercator projection, would be preferred. It would be the navigator's object to adopt the shortest route available, taking into account currents, winds, ice and other undesirable features of high latitudes, as well as specified lanes of traffic, and the intervention of land. Since the great circle route is always shorter than any other, especially between ports far apart in longitude and in high latitudes of the same name, a great circle chart is often used, for on such charts a great circle appears as a straight line. But since the track will be transferred finally from the great circle chart to one on a Mercator's projection, which is more convenient for purposes of navigation, the course may be entered in the beginning on a Mercator's chart using the method proposed by Airy for drawing approximate great circles. On a Mercator's chart the track followed by a ship steering a continuous course is a straight line (technically known as a rhumb line), and since ships rarely, if ever, steer on great circles and, instead, follow a series of rhumb lines like chords of the great circle track, differing successively one or two degrees in direction, it is desirable to use a Mercator's chart upon which each such course appears as a straight line.

Having thus planned the most advantageous general track to follow, three methods are used to determine the position of the ship at any time during the voyage. These are (1) projecting the track on charts, (2) simple trigonometrical calculations based upon the course steered and distance run as shown by compass and log, and (3) astronomical observations with sextant and azimuth circle.

Of these the first is generally least trustworthy owing to the unavoidably small scale of the charts. But when a ship approaches or leaves a coast, chart sailing becomes obligatory and large scale charts are available for the purpose.

On leaving harbors, the so-called point of departure is found, possibly by astronomical observations but preferably by sighting on objects on shore as mapped on the chart of the port. In hazy weather especially, a continuous line of soundings at fairly even distances apart affords an additional control on one's position, and for this purpose the sounding machines invented by Lord Kelvin, permitting satisfactory soundings at speeds of 15 or 16 knots, are most useful.

While in sight of land the course can be followed best by land sights and soundings, a method of navigation usually referred to as

piloting. Before losing sight of land the longitude and latitude of the last well-determined position found by methods of piloting is taken from the coast chart and transferred to the ocean or small scale chart and is considered as the point of departure.

The point of departure is the starting point of the ocean voyage; and from that point the course and distance are laid down, being rectified whenever astronomical observations are available. More accurately, though less vividly than on the chart, the changes in longitude and latitude involved in each change of course are computed by plane trigonometry, using so-called traverse tables for the solution of the right-angled triangle involved. Such a method of keeping account of a ship's position on the basis of the course as indicated by the compass and the distance as indicated by the log, allowing for wind, current, and tide, is called dead reckoning. As bearing upon the accuracy of the log, it is interesting to note that some authorities, in the case of steam vessels, consider that the revolutions of the ship's propeller, taking into account the ship's draught and the condition of the ship's bottom, afford the best means of estimating speed.

Astronomical reckoning affords the most accurate means of ascertaining positions at sea, dead reckoning being carried along partly as a check but also to be relied on when weather does not permit observations of the heavenly bodies.

Navigators will generally prefer to determine position from observations of the sun, measuring the altitude of that body above the sea horizon. But similar observations of the planets and brighter stars in twilight, when the horizon is well defined, afford even better determinations of positions at sea. In such a case the careful navigator, by observing for latitude two stars, one north and one south of the zenith, and for longitude two stars, one east and one west of the zenith can depend on a good result, especially if the stars in each pair are about at the same altitude and not too low in the sky. Since the moon also may be used when occasion arises, it is evident that the navigator seldom needs to go along without a good fix or determination of position.

The chief astronomical observations made at sea are those for ascertaining (1) latitude, (2) time and longitude, (3) compass error, and (4) latitude and longitude simultaneously.

The plan of many navigators is to observe with a sextant the altitude of the sun in the morning when that body is nearly above the east point, to determine local time and longitude. In the computation of local time it is necessary to adopt a latitude obtained by dead reckoning, but if the sun is well placed errors in the assumed latitude will introduce relatively small errors in the resulting ship's time. The longitude is obtained by taking the difference between the

ship's time and the corresponding Greenwich time recorded by the ship's chronometers. This longitude is carried forward to the following noon by dead reckoning. The latitude at noon is determined by measuring the altitude of the sun on or very near the meridian. Another time sight may be made before sunset. Or if stars are used at twilight one is observed east or west for longitude and another north or south for latitude. A longitude by dead reckoning may be used first to derive the latitude and then with the observed latitude the longitude may be obtained, though in unfavorable cases more trials may be necessary.

The newer methods, which are rapidly superseding other modes of ascertaining a ship's position, are based upon the use of the Sumner line of position. In these methods each sextant altitude of a heavenly body is used to determine all it ever can actually give, a line on the sea on which the ship must be situated. Such a line, though in practice nearly always sensibly straight, is in reality an arc of a small circle on the earth's surface having its center immediately under the celestial object observed with a radius equal to the zenith distance of that object. The Sumner line may be defined by two points, in which case two longitudes or two latitudes are assumed or based upon dead reckoning and the other coordinate computed from the celestial observation. Or the line may be defined by one point derived in this or a similar way from the celestial observation, together with the direction of the line, which will be at right angles to the direction of the body observed at the time of the observation. If the Sumner point, thus used in defining the Sumner line, is to be adopted as a point of departure, it is important that it should be a probable position, taking advantage of the evidence furnished by dead reckoning. In the Marc St. Hilaire method, which is generally preferred, this point is the intersection of the Sumner line with the vertical plane of the celestial object observed, assuming for the observer the position obtained by dead reckoning. Or, in other words, it is the point of the Sumner line nearest to the dead reckoning position.

Some help toward an understanding of Sumner's method will be found in an account of its discovery. Sumner sailed from Charleston, South Carolina, in November, 1837, bound for Greenock, England. After passing longitude 21° W, about 800 miles west of London, no observations could be made until soundings had indicated that the ship was near land. About midnight of December 17, dead reckoning indicated that the ship was within 40 miles of Tuskar light off the Irish coast opposite Wales, and the ship stood off the supposed shore to await developments. About 10 o'clock the next morning an altitude of the sun was observed and the chronometer time noted, but, having run so far by dead reckoning, it was plain

that the knowledge of the latitude was not sufficiently reliable to afford a determination of longitude. Nevertheless Sumner computed his longitude, using the latitude by dead reckoning, and got a position 15 minutes east of that by dead reckoning. Then in order to determine how far errors in his assumed latitude would affect the computed longitude he assumed a second latitude 10 minutes farther north and got a position 27 miles east northeast of the former position and toward the danger. A third assumed latitude still farther north gave a third point 27 miles still farther east northeast of the first point. Upon plotting these positions on a chart they were seen to be on a straight line and this line passed through Small's light off the coast of Wales. Credit is due Sumner because he realized then that anywhere on the line he had determined the altitude of the sun at the time of observation would have had the value he measured, and that such would be the case only on that line. He therefore assumed that he was on that line and, keeping his course east northeast along it, made Small's light in less than an hour. After hours of uncertainty off a rocky lee shore in the midst of a winter gale what must have been Captain Sumner's relief when the lighthouse appeared ahead. Later it developed that at the time of his uncertainty his latitude by dead reckoning was 8 miles too far south and his longitude 45 miles too far west. The result to the ship might have been disastrous had this wrong position been adopted.

In using Sumner's method in its simplest form, altitudes are measured of two suitable objects in quick succession or of the same object at two suitable times. Each observation gives a line upon which the ship must be situated. The intersection of these two lines of position gives the position of the ship. If the two observations are separated in time and the ship is moving, dead reckoning must be used to allow for the ship's change in position between observations.

Important advantages of the line of position methods are not hard to find. Every observation for position is treated in the same way. The method makes clear to the navigator how much information his observation actually yields. With available tables, including Lord Kelvin's Sumner Line Table, the calculations may be completed entirely without logarithms and with a minimum amount of work. When the value of the newer methods is realized by navigators it is not to be doubted that calculations for position will be based universally on the Sumner line.

In considering the foregoing methods of fixing astronomically the position of a ship it is evident that, always when the two elements of latitude and longitude are determined at different times and frequently when they are determined by Sumner's method, the navi-

gator has to depend partly on dead reckoning; also during cloudy weather out of sight of land he has to depend entirely on this method for his knowledge of the ship's position. Clearly then frequent determination of the error of the compass is a most important duty. In practice this error is found very simply by comparing the compass bearing or direction of a heavenly body with its bearing, determined by calculation if necessary, but usually taken from a table.

The total error of the compass includes that due to actual known variation of the needle and also that due to deviations caused by the attraction of the iron of the ship. The former error can be found from charts and easily allowed for, but the latter is variable and uncertain and thus makes necessary the frequent determination of compass correction. It is customary to reduce the deviation error as much as practicable by the use of artificial magnets, as well as spheres and bars of soft iron, mounted about the compass before the ship leaves port, but no arrangement known effects a permanent correction.

A careful record of everything pertaining to the navigation of the ship with the results of all observations and calculated positions is kept in an official book, called the ship's log. Each day at noon the ship's position is computed by dead reckoning from the previous noon and also by astronomical observations when such are available. The course and distance made good from the previous noon are then computed using astronomical position if available. Finally the course and distance are computed from the position of the ship at noon to either the port of destination or some prominent position or danger near which the vessel must pass.

The needs of our rapidly expanding naval forces and the demand of our new merchant fleet for thousands of officers have centered attention in instruction for the preparation of navigators. The shipping board schools, the naval schools and colleges, and also our universities are making a creditable effort to meet the situation. The concrete result in trained men will undoubtedly fill all important requirements. But in addition it is reasonable to think that progress in the improvement of the art of navigation, in this country at least, will be stimulated. Awkward relics of former times may be hurried aside. Such obstacles as the astronomical day may be removed. Certainly beneficial cooperation will follow in greater measure among navigators on vessels of the Navy and the Merchant Marine and those who are experts in related fields on shore.

THE TORNADOES OF THE UNITED STATES.¹

By Prof. ROBERT DE C. WARD,
Harvard University, Cambridge, Mass.

[With 1 plate.]

NATURE OF A TORNADO.

The relation of a tornado to human life and property depends upon its nature. What it *does* is determined by what it *is*. Briefly stated, a tornado is a very intense, progressive whirl, of small diameter, with inflowing winds, which increase tremendously in velocity as they near the center, developing there a counter-clockwise, vorticular, ascensional movement the violence of which exceeds that of any other known storm. From the violently agitated main cloud-mass above there usually hangs a writhing, funnel-shaped cloud, swinging to and fro, rising and descending. With a frightful roar comes the whirl, advancing almost always toward the northeast with the speed of a fast train (20 to 40 miles an hour or more), its wind velocities exceeding 100, 200, and probably sometimes 300 or more miles an hour; its path of destruction usually less than a quarter of a mile wide; its total life a matter of perhaps an hour or so. It is as ephemeral as it is intense.

Fortunately for man, tornadoes are short-lived, have a very narrow path of destruction, and are by no means equally intense throughout their course. Their funnel cloud, which indicates the region of maximum velocity of the whirling winds, ascends and descends irregularly. Where it descends, the destruction is greatest; where it rises, there are zones of greater safety. The whirl may be so far above the ground that it does no injury whatever. It may descend low enough to tear roofs and chimneys to pieces. It may come down to the ground and leave nothing standing.

DAMAGE AND LOSS OF LIFE IN TORNADOES.

The central low-pressure core of the tornado is surrounded by radially inflowing winds of moderate strength, and then, closer to the

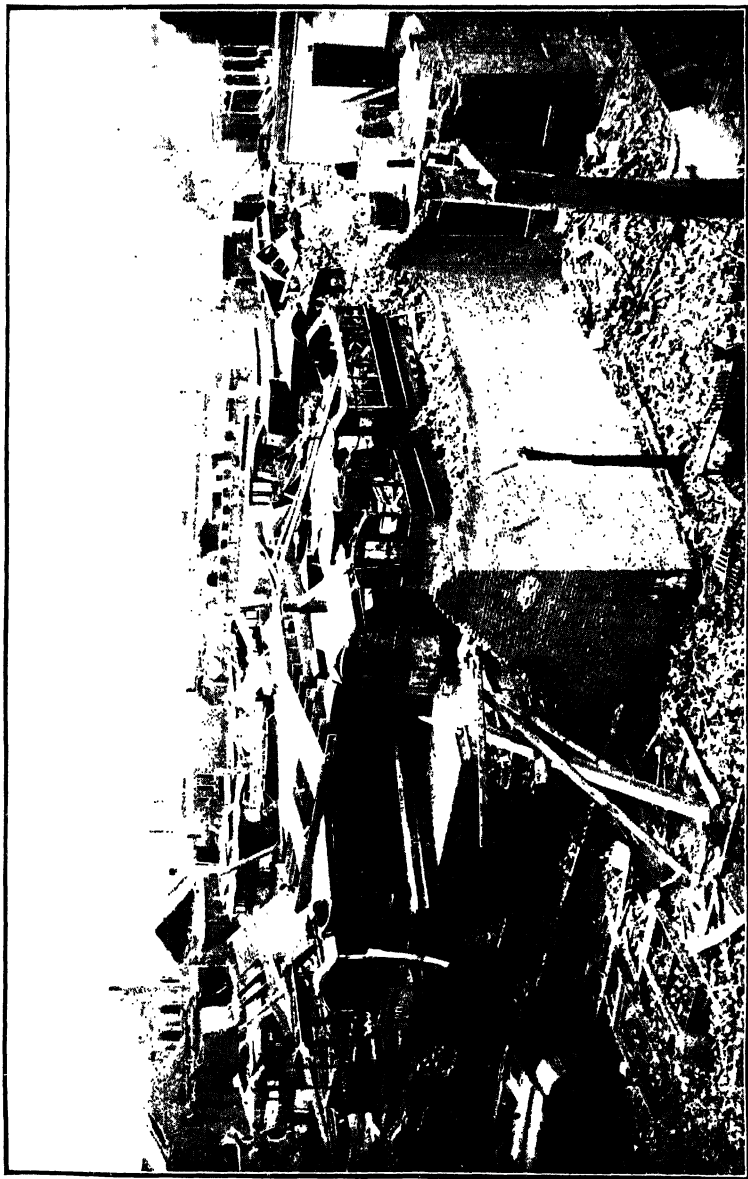
¹ Reprinted by permission from *Nature*, vol. 101, July 18, 1918, pp. 395-399; abridged by the author from *Quarterly Journal of the Royal Meteorological Society*, vol. 63, No. 183, July, 1917.

center, by spiraling and ascending winds of terrific violence; strong enough to crush and wreck the strongest buildings; ascending with sufficient velocity to carry aloft objects so heavy that for wind to lift them seems almost impossible. The surface winds which take part in the vorticular inflow and ascent seem to be chiefly responsible for the damage and loss of life. There is, however, an additional factor. The central "core," surrounded by its whirling winds, has its pressure greatly reduced by the centrifugal force of the whirl. It therefore exerts a powerful explosive effect upon near-by air at ordinary pressures, within buildings or in other more or less well-inclosed spaces. This curious but very widely-attested explosive effect accounts for many tornado "freaks" which can not be explained by any controls, either of radially or spirally inflowing winds, whatever their velocity.

The damage done by tornadoes may be roughly classified as follows: (1) That resulting from the violence of the surface winds, blowing over buildings and other exposed objects, crushing them, dashing them against each other, etc.; (2) that caused by the explosive action; and (3) that resulting from the uprushing air movement close around the central vortex. Carts, barn doors, cattle, iron chains, human beings, are carried through the air, whirled aloft, and dashed to the ground, or they may be dropped gently at considerable distances from the places where they are picked up. Iron bridges have been removed from their foundations; beams are driven into the ground; nails are forced head first into boards; cornstalks are driven partly through doors; harness is stripped from horses; clothing is torn from human beings and stripped into rags. The damage is greater and extends farther from the center on the right of the track than on the left, for the wind velocities are greater on the right. as in the "dangerous semicircle" on the right of the track of tropical cyclones.

The explosive effects are many and curious. The walls of buildings fall out, sometimes letting the roof collapse onto the foundations; or the roof may be blown off, leaving the walls standing. The accompanying photograph (pl. 1) illustrates some of the damage which was done by the St. Louis, Mo., tornado of May 27, 1896. The surface of the ground may be swept clean, as if with a broom. Articles may be blown out of houses and carried to great distances. Empty bottles are uncorked; feathers plucked from barnyard poultry; doors and windows blown out; soot rises from chimneys; mud penetrates clothing.

Property damage in the United States due to tornadoes varies greatly from year to year, depending, as it does, upon the "accidental" passage of tornadoes through well-populated or through sparsely settled districts. In half an hour the St. Louis tornado



ST. LOUIS, MO., TORNADO, MAY 27, 1896. WRECK OF CAR BARN.

From the Quarterly Journal of the Royal Meteorological Society.

(May 27, 1896) destroyed property to the amount of \$10,000,000 in St. Louis alone. In some years the damage for the whole United States falls to but a few hundred thousand dollars.

Figure 1 illustrates the tragic fate of one family in a tornado (May 30, 1879).¹ A house was moved entirely from its foundation to the southeast, then broken to pieces and scattered along the tornado track to the northeast for more than a mile. The members of the household, consisting of father, mother, and four children, ran outdoors as the storm came. They first turned northwest, but, thinking that the tornado was coming toward them, they turned toward the east. One by one they were caught up and carried by the wind. The father and baby were carried 150 yards into a field to the northeast, and found in the agonies of death. The mother was carried eastward 75 yards, and dashed against a tree, around which she was partially twisted; her skull was crushed and her clothing was stripped from her body. A girl was found dead 50 yards northeast of the house, in the direct path of the storm. A boy was blown into a haystack 45 yards to the northeast, and a girl was found 80 yards to the northeast lying in the tornado track. Neither of these two children was seriously injured. Disasters similar to this one come all too frequently in the American tornado belt.

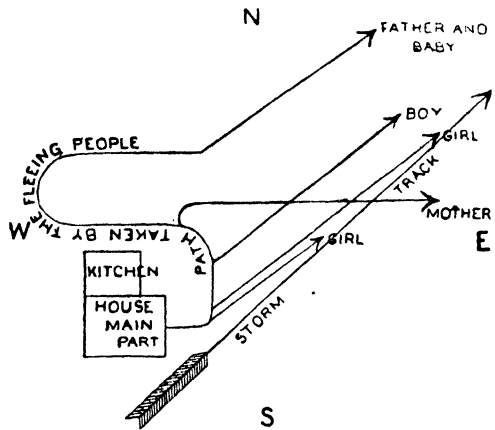


FIG. 1.—Tornado, May 30, 1879. From the Quarterly Journal of the Royal Meteorological Society.

Finley listed some 600 tornadoes, of which 40 were fatal to human life, causing a loss of 466 lives and injuring 687 persons.² In the case of the St. Louis tornado (May 27, 1896) the loss of life was 306. In fact, in this one storm the fatalities and the damage to property were greater than in any other single tornado on record. Prof. Mark W. Harrington, formerly chief of the United States Weather Bureau, estimated that the chance that a tornado may, in any year, cross the particular locality where any individual may

¹ J. P. Finley, "Report of the Tornadoes of May 29 and 30 in the States of Kansas, Missouri, Nebraska, and Iowa." Professional Papers, United States Signal Service, No. IV, (Washington, D. C., 1881.)

² J. P. Finley, "Report on the Character of Six Hundred Tornadoes," Professional Papers, United States Signal Service, No. VII. (Washington D. C., 1884.)

happen to be is 1 in 625,000, and "not worth worrying about."¹ The late Prof. Cleveland Abbe concluded that even in the so-called "tornado States" the probability of tornado destruction is less than that of lightning or fire.²

DISTRIBUTION OF TORNADOES IN PLACE AND TIME.

The real home of the tornado is over the great lowlands east and west of the central and upper Mississippi and of the lower Missouri valleys, and, to a less marked degree, over some of the Southern States. Tornadoes are rare west of the one hundredth meridian, and very rare or unknown in the mountain areas. They have been reported from all States east of the Plains, but decrease markedly in frequency toward the north. They are rare in the Appalachian Mountains, and also infrequent along the Atlantic and Gulf coasts. The widespread impression that tornadoes are increasing in number in the United States is without foundation of fact. Tornadoes are reported with greater accuracy than formerly, and they are likely to do more damage than they used to do because the country is more densely populated.

Tornadoes may appear in any month and at almost any hour of the day or night. Like thunderstorms, however, they distinctly prefer the warmer months, and the hours closely following the warmest part of the day. Thus spring and early summer (April to July) and 3 to 5 p. m. are their favorite times.

TORNADO WEATHER TYPES.

Tornadoes have much in common with thunderstorms. In fact, they are, in reality, special local developments, of greater violence, in connection with severe thunderstorms. The general conditions which produce these two phenomena are, to a large extent, identical. The essential difference comes in the formation of the vorticular whirl in the tornado. Thus, like the largest and most severe American thunderstorms, tornadoes occur as attendants of the parent cyclones of which they are the offspring. They are born, in the large majority of cases, in the area of warm, damp southerly winds flowing northward from the Gulf of Mexico in front of a general cyclonic storm. This storm is usually more or less elliptical or V-shaped, its major axis extending north to south or northeast to southwest from the Great Lakes, across the central lowlands well into the Southern States. The "wind-shift line" or "critical axis" is usually well marked. North and west of the wind-shift line northerly to westerly winds are blowing with relatively low temperatures, and

¹ M. W. Harrington, "About the Weather," p. 164 (N. Y., 1890).

² Cleveland Abbe, "Tornado Frequency per Unit Area," *Monthly Weather Review*, vol. xxv, p. 250. (Washington, D. C., June, 1897.)

not infrequently with rain or snow. South and east of the critical axis there is a great flow of southerly or southwesterly winds with higher temperatures, usually sultry and oppressive weather, and often with rain squalls. When conditions are favorable, tornadoes are likely to occur in a district some 300, 400, 500, or more miles to the southeast, south, or southwest of the cyclonic center, near, but usually to the east of, the wind-shift line. Here the contrast between the warm, damp southerly and the cool, dry northerly and westerly winds is sharp. Here is inevitably a zone of great disturbance; of overrunning, underrunning, and mixing; of turbulence; of instability; of local whirls. Here, aided by the local warming due to sunshine, are favorable conditions for breeding thunderstorms and, fortunately much less often, for developing tornadoes.

The parent cyclone may travel many thousands of miles, a good part of the way round the world, yet in only one portion of its long course, in the Mississippi Valley region of the United States, and usually only at one time of the year, in spring and summer, is just the right combination of conditions attained for developing the dreaded tornado.

PROTECTION OF LIFE.

The possible protection and preservation of human life in tornadoes are very real and vital questions over large areas of the United States. From a long and intimate study of tornadoes, Finley deduced certain rules for the protection of life which have over and over again proved their accuracy and value. If a tornado is approaching from west or southwest, and the observer is on or very near its probable path, the best thing to do, if there is time, is to run north. "Dugouts" or tornado-cellars should be provided near the house. The safety secured by means of "dugouts" is that they remove persons who seek refuge in them from risk of injury from flying débris; also from the danger of being picked up by the winds.

If there is no time to escape, the safest place is to stand, face forward, against the west or south wall of the cellar, as near the southwest corner as possible. The reason for these precautions is this, that the débris of the house will, if the building is destroyed, be more likely to be carried toward the northeast. Hence northeast or east rooms and walls are least safe. If caught outdoors, and otherwise unable to escape, the best thing to do, as a last resort, is to lie flat on the ground in an open space, face downwards, the head to the east, and the arms placed over the head for protection.

PROTECTION OF PROPERTY: TORNADO INSURANCE.

In regard to the protection of property certain things are fairly clear. Tornadoes can not possibly be prevented, and no buildings, certainly

none of any practical use, can be built to withstand the violence of the wind in the vortex of a well-developed tornado. Hence the only resource left is to protect life and property to the best of our ability and with a knowledge of the facts which have been brought to light by a sane, unprejudiced, scientific study of the phenomena. Owing to the varying intensity of tornado violence and of the velocity of the surface winds, the damage done to different sorts of buildings varies greatly. If the intensity of the storm is not sufficiently great to destroy everything in its path, the damage done by the less violent winds will obviously depend largely upon the strength of construction and upon the building materials. It was Finley's advice to build "as you would without the knowledge of a tornado." He found, however, that, other things being equal, a frame building seems to resist destruction better than one of brick or stone. The modern steel-construction buildings have some of the "elastic" quality which renders frame structures safer than the more stable and solid ones of stone or brick of the older style. It makes little or no difference in the end whether a building is in a valley or on a hill.

In view of the property loss occasioned by tornadoes it is natural that tornado insurance has become a widespread and popular method of financial protection. So far, however, the business has not been carried on upon a thoroughly scientific basis. Tornado insurance to the amount of several hundred millions of dollars is carried, largely by general fire insurance companies, and partly by local mutual insurance companies. The definition of a tornado is usually crude and unscientific, and there is much unnecessary confusion. It is true that the more conservative companies do prohibit some "risks," such as windmills, old and frail buildings, large plate-glass windows, and the like. It is interesting to note the marked rise and fall of the amount of tornado insurance with the occurrence in any year of severe or destructive tornadoes. Closely following the St. Louis tornado of May, 1896, there was an increase of tornado insurance of nearly \$10,000,000, and after the Omaha (Nebraska) tornado of Easter Sunday, 1913, several million dollars' worth of tornado insurance was written in Omaha and the surrounding districts, which were at once thoroughly canvassed by insurance agents. Many new dugouts and cellar caves were built at the same time. As Prof. H. E. Simpson¹ has pointed out, tornado insurance risks differ from others in several ways, notably in the fact that there is no criminal hazard present; for people can not remove, or explode, or destroy their buildings for the sake of the insurance, on the plea that the damage was done by a tornado. It is obviously wise to scatter

¹ H. E. Simpson, "Tornado Insurance." *Monthly Weather Review*, vol. xxxiii., pp. 534-539. (Washington, D. C., December, 1905.) A short bibliography is appended.

tornado risks across, not along, the usual path followed by tornadoes. The complete destruction often caused by a single tornado makes it extremely unsafe for any local mutual insurance company to insure over a small area only, where the loss occasioned by one tornado may ruin the company. On the whole, general tornado insurance in the "tornado belt," and buildings erected without regard to the possibility of tornado occurrence, seem to be the best policy. The present status of tornado insurance in the United States is an excellent illustration of the mistakes which are made when thoroughly well-established scientific facts, which are easily accessible to the public, are disregarded.

WIND POWER.¹

By JAMES CARLILL.

There used to be windmills; why have they gone? Those who watched their gradual disappearance probably looked upon it as a sign that the age of steam had superseded the age of wind. But the explanation is inadequate. There were a great many factors involved in the decay of the old windmills. They were, in the first place, costly to build, involving the erection of a lofty tower standing on a considerable area of land; then they were difficult to manage, the process of reefing in bad weather being attended with many accidents and not seldom with loss of life; again, they were uneconomical in working, utilizing but a small fraction of the available wind energy; they were seldom erected in the most favorable positions, and were most numerous in those parts of the country in which our wind power is least exhibited. But the most potent cause of the decay was a growing preference on the part of the public for a white loaf made of blended flour; this it was which finally gave an overwhelming advantage to the steam mills situate near the ports of entry for foreign grain.

Still, the windmill never quite ceased to exist; it continued to do pumping work in the Cornish mines and in the Lincolnshire fens; and its great utility as a pumping agent led to its revival in an altered form for this particular purpose. Small mills on steel frames, of what is known as the American type, began to appear in our nursery gardens, in private estates, in farmsteads, and even in public undertakings, until, at the present day, there are more windmills working in England than there were 60 years ago. No doubt their use for public water works would have been more extensive but for the regulation of the local government board which practically forbade district councils to use them unless accompanied by auxiliary steam power. The regulation seems a little difficult to justify, except on the principle that it is better to have no water at all rather than to have it for six days out of seven. Those councils who have complied with the stipulation of the board have usually found that the auxiliary plant has not been required.

Two instances will suffice to show the very substantial nature of the work accomplished by these pumping engines. One windmill,

¹ Reprinted by permission from *The Edinburgh Review*, October, 1918.

40 feet in diameter, erected by a private firm on an estate in Yorkshire, raises during a steady breeze 3,000,000 gallons of water through a height of 10 feet in 24 hours. Another mill of similar dimensions installed by a district council to supplement a steam pumping plant has saved the council 200 tons of coal per annum and has cost nothing in upkeep. It may seem strange that a power showing such substantial results should not have been applied to other purposes. But it may be remembered that for many years after Watt's inventions the steam engine still continued to be used for no other purpose than pumping. And in the case of the wind-mill there are certain specific drawbacks which have militated against its general adoption as a prime mover.

The first defect is that the power hitherto obtained has been but a small fraction of the available wind energy. The old corn mill probably did not extract more than 5 per cent of the energy theoretically obtainable from wind pressure on its sail area. The modern or American type does better, perhaps to the extent of 10 or 12 per cent of the available energy, but not more. The figures quoted above (30,000,000 foot-gallons a day) sound large, but they do not represent more than 7 horsepower, as against 40 horsepower which might be obtained from a thoroughly efficient wind engine of equivalent area.

In the second place, the speed of the sails at their circumference is greater than the speed of the wind, and it increases without limit, so that in violent storms the disruption point is reached. In the old type that was avoided only by reefing; in the American type it is avoided by adjusting the inclination of the vanes; but in neither case is safety assured. The chance of being wrecked by storms has led to a preference for small mills.

In the third place, the variability of the power, while it does not matter for pumping, is a stumbling block in the way of direct machine driving. So long as the mill is pumping only it does not matter whether it is pumping faster or slower; but if it were driving a circular saw or a loom some provision would have to be made for adjusting the speed to tolerable uniformity.

Three things are therefore desirable in a really efficient engine: First, the devising of a motor which would utilize more of the wind energy; secondly, the invention of means of regulating speed; and thirdly, the devising of some means of storing power. All these requirements have now been met.

In 1881 Lord Kelvin (then Sir W. Thomson) referred to the subject of wind-power utilization at the meeting of the British association. He pointed out that since the invention of storage batteries there was no longer any need to neglect such an important natural source of energy since the surplus power of a period of high winds

could be accumulated and utilized in a period of calms. Acting upon this hint, one of Lord Kelvin's pupils, James Blyth (afterwards professor at Glasgow Andersonian College) made a series of experiments which led to the construction of a very efficient and economical wind motor. Bernoulli and Maclaurin had shown that in theory the most efficient form for a windmill would be a cup or box consisting of half a sphere or half a cylinder revolving in the line of the wind. Robertson adopted this type for his anemometer, the four cups of which are familiar objects at our observing stations. These four cups constitute a body revolving in a resisting medium, and can not exceed a certain limiting speed. In the usual form of anemometer that speed is one-third that of the wind.

Upon this sound theoretical foundation Professor Blyth saw the possibility of designing a wind motor which would develop more power than the old sails, while it would be more economical in construction and free from their defects in working. For the cups of the anemometer he substituted boxes, semicircular in section, which he mounted on arms extending at right angles from the shaft. Using boxes 10 by 6 feet, he found that his motor developed eight horsepower in a very moderate breeze, and, moreover, it justified his expectations in other respects, and could be left free to run by itself in the strongest gales without suffering injury. After using his mill for some years for the purpose of electric lighting, Professor Blyth was sanguine enough to prophesy that before long electric light and power would be supplied over a large part of Great Britain by the use of wind engines on his model.

Possibly the inventor's early death led to the oblivion which his invention has suffered. More probably the neglect is due to our preoccupation with the ideas of coal and steam, which lead us to contemplate any alternative source of power with a smile of derision. We have grown accustomed to regard the hewing and carrying and burning of coal as the first essential of industry and even of life, and have regarded the multiplication of railway sidings with their miles of laden or empty trucks as signs of material prosperity. But the war has opened our eyes on this subject as on others, and in some measure we are prepared for the conclusion that the internal transport of coal is a wasteful and disagreeable necessity which in a well-ordered community would be reduced to a minimum. And when, in addition, we are confronted with a rise in price to at least double its pre-war quotation, the question of an alternative source of power which does not need railway transport and storage, and does not require the assistance of highly paid middlemen and brokers, becomes a question of truly practical politics. There ought, therefore, to be a chance for the element which has so often befriended us.

The first consideration is whether we have a sufficiency of wind-power presented to us by Nature in these islands. It is the firm conviction of the land dweller that nothing is more uncertain or inconstant than the wind; and even the yachtsman would agree with him that there are times of provoking calm and seasons of needless activity. But neither the pedestrian nor the yachtsman is an adequate authority. Calm as it may seem on land or on the surface of the water, there is almost always a movement of the upper air. The records of the too short-lived observatory on Ben Nevis disclosed many occasions on which the observers had to struggle, roped together, against an 80-knot breeze at a time when scarcely a ripple disturbed the surface of Loch Linnhe below. The records of American observatories confirm the conclusion that wind speed uniformly increases with the elevation at which it is recorded.

Even near the ground a condition of absolute calm is rarer than would be anticipated. The longest continuous records that we have are those of Greenwich Observatory, and they show an average of 15 days calm in a year. But the Greenwich anemometer is not favorably placed, being unduly sheltered from the south and southwest, and it is quite certain that if it were 50 feet higher its record of calm would be diminished. It seems probable that at a height of 100 feet from the ground the existence of absolute calm is an event of extreme rarity, and that if we could place a wind motor at a height of 1,000 feet above the surrounding land we could rely on its working for nineteen-twentieths of the time.

The records of the meteorological office furnish us with actual experience of the wind movement at different observing stations for several years past. Some of these stations are, it is true, badly placed, and their instruments are not so favorably situated as a windmill would be; but they are for that reason a safe guide to the minimum of expectation. The following facts emerge clearly from the records. Our prevalent winds are southwesterly, or a few points on each side; these occur on 188 days in each year. It is therefore obvious that the area in which the best windpower is developed lies on or near our western coasts. On the other hand, the easterly breezes which are felt most strongly on the eastern coasts do not lose quite so much of their force in passing over the midlands as do the southwesterly winds, which are partially intercepted by the higher ground of our western counties. There are, therefore, three zones of decreasing wind strength, the western coasts being the highest, next, the eastern coasts, and last, the midlands. Taking the average of seven observatories near the western and southern coasts, it appears that a wind velocity of 4 miles an hour and upward is experienced during 7,450 hours out of the 8,760 hours in a year, and the wind velocity most frequently recorded is from 15 to 17 miles

an hour. Again, taking the average of nine observatories on the eastern coasts and inland, a wind velocity of 4 miles an hour and upward is experienced for 7,106 hours in 12 months, and the most usual velocity experienced at these stations lies between 11 and 13 miles an hour. In both areas there are certain stations at which these figures are much exceeded, some places recording a working breeze for more than 8,000 hours, and one or two stations giving a most usual wind speed of 19 miles an hour. For the reason already given the average both in duration and intensity may safely be taken as an underestimate.

It is clear that a power which is presented to us in such quantity is worth using for purposes other than pumping, and that wind-power stations might with great economical advantage be established in all those parts of our islands which are remote from the coal-fields. The objection from an engineering point of view would doubtless be that such power would have to be developed in small units. If the only object in generating power were to use it on a large scale such an objection would be conclusive. We are never likely to construct a wind engine which would develop even a thousand horse-power at one spot; and there are of course certain specific objects for which a larger power than this is required, such, for instance, as the extraction of nitrogen from the atmosphere, or the preparation of aluminum. But if the power at the generating station is required simply for the purpose of distribution in small units over a large area, then the object might equally be attained by local generation in small quantities. It becomes purely a question of economy, in which the determining factors are the original cost of construction, the expense of maintenance, and the loss of power through leakage in transmission.

It is these factors which distinguish the case of electric generation in industrial districts. Here there is power required which must be got from coal; it is required, moreover, in different quantities, for different purposes, and in different parts of a certain well-defined area. It would be wasteful in the extreme—or, rather, we should say it is wasteful in the extreme—to have a number of generating stations working on different systems, serving adjoining portions of the area. The committee which has been investigating this subject has presented a report in which there is no trace of doubt, reservation, or hesitation whatever. It shows that our existing system of electrical generation involves an absolute waste of 50,000,000 tons of coal a year. There are 600 electrical undertakings in Great Britain, and their average size is one-thirtieth of the size of a really economical power-station unit. In only one part of England has an ideal electrical station been established, and that is on the north-east coast, with Newcastle as its headquarters. Electrical power is

available all over this area for less than a halfpenny a unit. Compare this with Lancashire, a larger and more densely populated area—in fact, the greatest industrial area in the world. In Lancashire there are 23 borough generating stations, and the charges per unit vary from three times to six times the charge in the Newcastle area. There can be no doubt that if the Lancashire district were supplied from one center the cost of electric power in the county would instantly sink to even less than the price in Newcastle.

The attention of our engineers has very naturally been directed to the generation of power from coal or falling water. Nor can anything be more completely satisfactory than a water-power station in a situation where nature has provided the necessary head. But in our islands such opportunities exist only in small and isolated units, and the fluctuating character of our waterfalls is sufficient to convince us that the construction of a large installation is at the best a doubtful experiment. The amount of our rainfall is easily exaggerated. Figures of 130 inches taken from one locality in Cumberland, and 100 inches from one locality in Inverness, seem to show that the quantity is sufficient to justify a large experiment. But as a fact the areas over which such a fall occurs are exceedingly circumscribed. There are only five small patches of ground in which an average fall of more than 80 inches is recorded—one in the lake district, one in the Snowden range, one in Ross, and one in Inverness; there may be a sixth not yet identified. But even including those isolated patches there are only nine stations in Great Britain in which an average fall exceeding 60 inches has been recorded. It is therefore evident that in order to secure a steady head of water for a large installation, an extensive area has to be inclosed and converted into a water-tight reservoir. The recent project of the aluminum company involved the inclosure of 250 square miles of country, and the expenditure of 2,500,000 sterling. And, after all, it would have given employment to but a handful of people; whereas the expenditure of the same capital on 2,000 separate wind-power stations might conceivably double the productive capacity of a considerable section of the population.

There is, however, a possibility of providing water power on a large scale on the coasts of these islands, provided only that we use sea water and employ windmills to pump it. There are on the western coasts certain inlets with narrow entrance and considerable internal capacity. If the entrance were closed, up to the summit of the cliffs, a windmill or two on the top of the sea wall would suffice to maintain a head of 150 feet of water. The cost of construction would be trifling when compared with the cost of an inland power station, while the cost of upkeep would be very small. There

is one such fjord which, so treated, would furnish a power station comparable with any in Europe, but for the sake of our dwindling scenes of peaceful beauty we may hope that it will escape the notice of the large-power enthusiasts; for all England is not yet an industrial area, and we need something which, without involving the extension of the industrial areas, will render our handiwork more productive in the village and the countryside which yet remains unspoilt.

Let us imagine one form which a wind-power station might take. A steel shaft with four semicylindrical boxes at right angles, the shaft revolving in a cup which is itself secured by four chains extending to the ground, would constitute the motor, and it would be entirely unconnected with the main building except by the belting from the flywheel below to the shafting in the machinery annex. The millhouse would consist of the central hall through which the shaft rises and in which the flywheel revolves. The four annexes would diverge from this central hall. One would contain dynamo and gear, accumulator cells, and other electrical equipment; a second would contain circular saw, planing machine, and other wood-working appliances; a third would be devoted to chaff cutters, grindstone, root-pulpers, and other agricultural machinery; and the fourth would be reserved for looms, heavy sewing machines, or any other machinery likely to be in special demand in the district. When there was a working wind, power could be communicated direct to the shafting in one or other of the machine rooms; and when the machines were not in actual use it could be communicated through the dynamo to the accumulator cells, or else could be utilized to pump water into an elevated reservoir. If both reservoir and batteries were fully charged the belting could be withdrawn and the shaft left to revolve by itself.

The ground space occupied by such an installation need not exceed 2 acres; the building would require little strength or solidity, and might be constructed of the partition blocks with which necessity has recently made us familiar; the whole installation, of dimensions capable of giving 40 horsepower with a 15 mile breeze, could be erected for a few hundred pounds. If such a powerhouse were built in a suitable locality, it would not take many months to outlive the first period of ridicule and neglect, and within two years many parish and district councils would desire to become possessed of their own stations, from which they could supply electric light and power in their own neighborhood, and in which they could let the use of specific machinery at so much per unit or per hour.

There is even a possibility of the employment of windpower on a larger scale. In Denmark, where small wind installations have been

at work for some years and where they have lately increased rapidly in number, a station intended to develop 200 horsepower is now in contemplation for the use of a bacon factory. The project may be too ambitious, but that it should be in contemplation is proof that the plan has been a commercial success in a country in which the average windpower is decidedly less than in Great Britain. And it may be added that certain devices recently invented by Prof. La Cour of Copenhagen have completely solved the mechanical difficulties in the way of adjusting the variable power of the motor to the working of a dynamo without injury to the accumulators from any sudden drop in wind energy.

Meanwhile the winds have another call upon us—a call from the sea, no less insistent than that on land. They are constantly reminding us that we are an island people with vast dominions across the seas, and that our home is not only these islands but also these possessions and the ocean which lies between. In the Crown colonies there are territories which have been in our possession for 150 years—territories teeming with produce awaiting our handling, and yet in whose ports a British ship is rarely seen. Trade has not followed the flag, and one reason is that the sailing vessel has been neglected to the point of disappearance.

Here, again, as in the case of the windmill, it is advisable to consider the specific causes of disuse. Let us carry our minds back to the year 1830. A committee of the House of Commons was then sitting to consider the possibility of sending the Dublin and Holyhead mail by steamer. This, be it remembered, was nearly a generation after Fulton and Synington, and at a time when steamers had been plying on the Mississippi for 20 years. It was the time, moreover, when the experts, headed by Doctor Lardner, had demonstrated to their own satisfaction that useful as a steamer might be on a river it could not possibly undertake a long ocean voyage. Up to that time the winds had not merely ground our corn, but had borne all our ocean traffic, maintained our colonial connections, conducted our commerce, won our naval victories, and established our position in the world. "Sea power," to use Mahan's phrase, then resolved itself into capacity for utilizing wind power. It is largely the truth that our Empire was created, preserved, and sustained by our skillful use of the wind. But that era was already drawing to a close. With the improvement of marine engines, and especially with the great economy in fuel following the introduction of compound engines, Dr. Lardner's prediction that the steamer could not provide cargo space was falsified, although it was a perfectly reasonable objection at the time it was uttered.

There followed a period in which the sailing ship was so far developed and improved that it frequently distanced the steamer boat and

on the same voyage. But the screw and the compound engine together decided the issue of the duel. Then came the question whether the new power could not be used in combination with sails. Many experiments, now forgotten, were tried with this object. The navy was very unwilling to part with the power which had so long been its prime mover. Even merchant shipowners were reluctant to part with the clippers which had built up their commerce. But in the course of experiments to combine sail and steam it became apparent that the space demanded by engine and boilers and bunker coal, together with the quarters of an engineering staff in addition to the large number of hands required by a full-rigged ship, were too great a tax on the cubic capacity of the hull and left little space available for cargo.

Now, if we consider the conditions of the problem we shall see that they have much altered since the days when it was dismissed as impracticable. The invention of the internal combustion engine with oil as fuel has reduced the space taken up by the engines by nine-tenths. It is now possible to fit a sailing ship with auxiliary screw and oil engines without interfering materially with her carrying capacity, and experimental voyages undertaken by the firm of Preuthout le Bland, of Havre, have demonstrated the commercial economy of the sailing ship so equipped. Moreover, for certain voyages—routes in which the trade winds play an important part—it has been demonstrated both by German and French shipowners, before the war, that it is actually cheaper to tow a sailing vessel to the trades than to employ steam for the whole voyage. *A fortiori* with coal at double the price the advantage will be greater.

It has now become a matter of importance to us that our coal reserves should not be wasted in work which can be done equally well by power which is supplied to us gratuitously. Of the 20,000,000 tons of coal which we annually export to our coaling stations abroad, a considerable portion might be carried by the wind, just as well as by steam. Part also of our annual imports might without disadvantage be carried by the same agency. But an even more important consideration is the opening up of trade routes to certain of our crown colonies which are neglected by the steamship because they do not afford sufficient opening for regular periodical voyages. In these smaller trades to out-of-the-way places there is undoubted scope for sailing ships fitted with auxiliary petrol engines. There is a considerable field of enterprise which is open to the sailing ship without challenging by direct competition the lines of traffic already occupied by steamship companies. And it is moreover a field in which the ancient spirit of the merchant adventurer may be revived.

Ever since the complete triumph of steam the tendency of merchant shipping has been toward consolidation, combination, amalga-

mation of rival companies, and the like forms of monopoly. Competition and commercial rivalry are becoming extinct, and the ocean, like the land, is parcelled out into spheres of influence and zones of exclusive dealing. The sailing vessel alone furnishes the chance for the small capitalist. It can be built at a more moderate outlay, its upkeep costs far less, it deteriorates less rapidly, and may still keep the water long years after the steamer has been broken up for scrap iron. A sailing vessel gives a chance to cooperative enterprise, for there is no reason why the profit sharing, which was the basis of the old whaling voyages, should not be applied to every trading voyage. Just as the ship may be owned by 64 individuals, so the profits of the voyage may be shared by the adventurers, the master, and the hands, every one having his personal profit in the success of the voyage. Under such a system the merchant service would receive a great impetus. It would attract a higher type of recruits and it would call forth and educate their best qualities. After all, Great Britain is and will be what her seamen make of her and what she makes of her seamen. So long as her young men desire to go to sea, and so long as she treats them well when they have entered on her service, be it naval or mercantile, so long is Great Britain's position among nations secure, even against the enhanced rivalry with which we are threatened after the war.



SAMUEL PIERPONT LANGLEY.

A TRIBUTE.—SAMUEL PIERPONT LANGLEY: PIONEER IN PRACTICAL AVIATION.¹

By HENRY LEFFMANN, *Member of the Franklin Institute.*

[With 9 plates.]

It may be safely assumed, I think, that mankind from its earliest period of self-consciousness had aspirations of flying. In primitive times birds were more abundant and varied than at present, at least in civilized countries, and the ease and grace of their flight must have profoundly impressed the rudest races. The legend of Icarus and his waxen wings is one of the expressions of this feeling. Among the world-wide and very ancient witchcraft legends we find the gift of flying a usual feature. In the later phases of these superstitions, especially as they appear in English-speaking nations, the highly unromantic method of broomstick flight is eminently characteristic.

Notwithstanding all aspirations, no practical method of flight by human beings can be demonstrated until 1783, when the brothers Montgolfier sent up a hot-air balloon. Hydrogen gas was soon after substituted for air, and the balloon in substantially its present form was produced. The standard form of balloon, however, does not fly in the full sense of the word; it simply floats in the air, subject to the currents thereof. Its modification, the dirigible, which has acquired such prominence in recent years, especially in the form known as the Zeppelin, has solved some of the problems of flight, but it is an expensive, complicated, and untrustworthy form, and has very limited practical application.

All creatures that fly are heavier than air, and this leads to the view that it will be by the method they use—namely, reaction upon the air as a material substance—that true flight will be obtained.

This was Langley's view, and it is to his honor that he insisted on this principle, and pointed the way, both in theory and practice, to its accomplishment. It is the purpose of this paper to summarize his main work, and to present his claims to the gratitude and admiration of the American people. The history of the later years of his life,

¹ Presented at a meeting of the Alumni Association of the Franklin Institute, held Thursday, Oct. 31, 1918. Reprinted by permission from the Journal of the Franklin Institute, vol. 187, No. 1, January, 1919.

when he was approaching the solution of the problem, in fact, had attained it, is one of the tragedies of science, and a painful reminder of the gap that still exists between the true scientist and the mass of the community, even in highly civilized lands.

It would, however, be inaccurate to claim for Langley absolute priority for the idea that a heavier-than-air machine can be made to fly. To think of an invention is a simple mental effort, and there are few of the great inventions or discoveries of the modern time that can not be found foreshadowed in the records of the past. A Greek poet describes in set terms the invention of submarine warfare, when Scyllus and his daughter, expert swimmers, dived at the sides of Xerxes' ships, cut the mooring cables, and thus caused many ships to drift to their destruction.

About the time of the discovery of America that remarkable and versatile genius, Leonardo Da Vinci, wrote an essay on the flight of birds, and referred to the possibility of human flight. I have not been able to consult the original essay, but notes thereon, by Da Vinci, have been translated,¹ and from this text I make a few selections:

I have divided the *Treatise on Birds* into four books: of which the first treats of their flight by beating their wings; the second of flight without beating the wings, and with the help of the wind; the third of flight in general, such as that of birds, bats, fishes, animals, and insects; the last of the mechanism of this movement. * * *

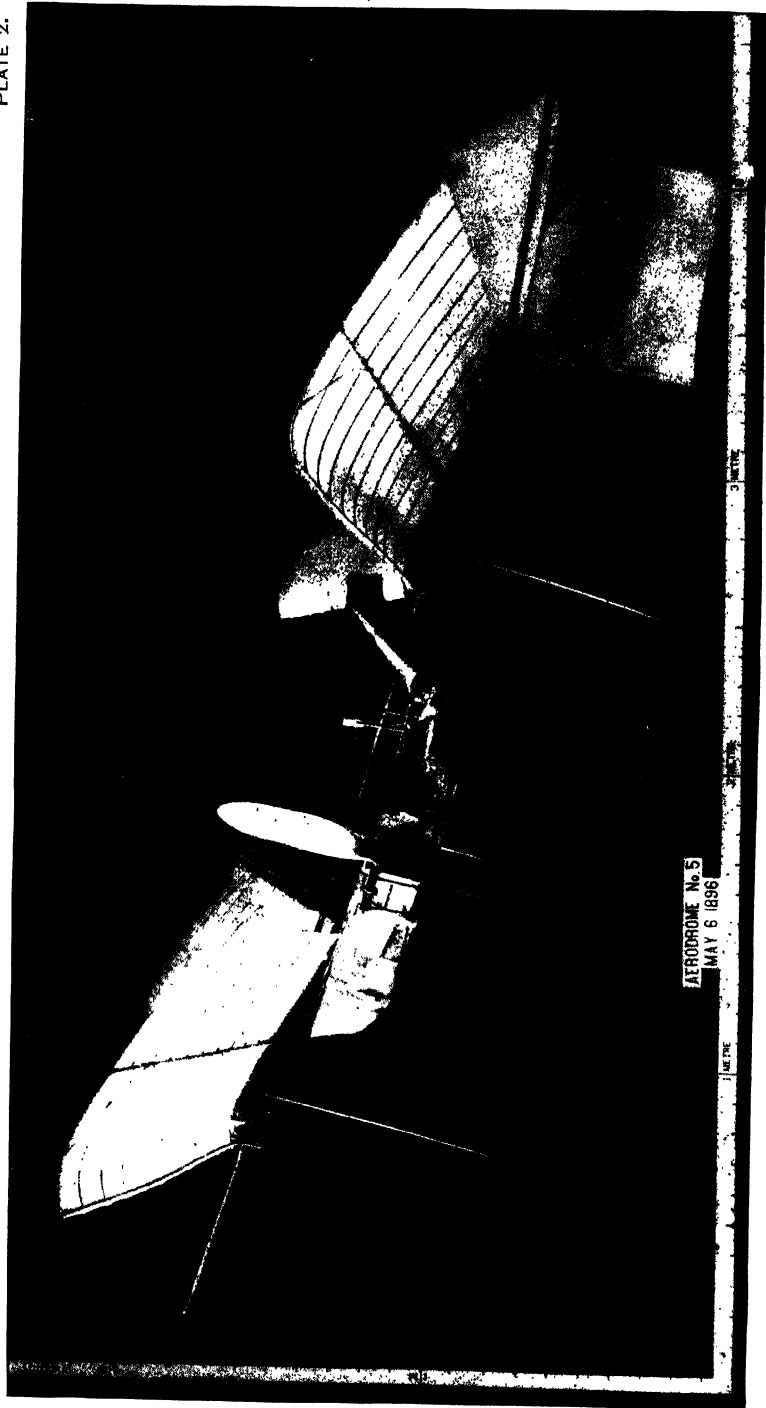
Remember that your bird should have no other model than that of the bat, because its membranes serve as armor, or rather as a means of binding together the pieces of its armor, that is the framework of the wings. * * * The bat is aided by the membrane which binds the whole together, and is not penetrated by the air.

Dissect the bat, study it carefully, and on this model construct the machine.

The bird I have described ought to be able by the help of the wind to rise to a great height, and this will prove to be its safety; since even if all the above-mentioned revolutions were to befall it, it would still have time to regain its equilibrium; provided that its various parts have a great power of resistance, so that they can safely withstand the fury and violence of the descent, by the aid of the defences which I have mentioned; and the joints should be made of strong tanned hide, and sewn with cords of very strong raw silk. And let no one encumber himself with iron bands, for these are soon broken at the joints, or else they become worn out, and consequently it is well not to encumber one's self with them.

It will be seen from these quotations that Da Vinci's plan was to equip a man with wings to be operated by his muscles, probably those of both legs and arms, for in another note he states that the muscles of the legs are much more powerful than the ordinary work done by them requires. He did not contemplate the use of machinery. It must be borne in mind that in that day, no powerful, portable prime mover was known.

¹ Leonardo Da Vinci's Note Books. Translated by Edward McCurdy, A. M. London, Duckworth & Co., 1906.



AERODROME NO. 5.

The first successful flight by a heavier-than-air machine, driven by its own power, was made by this machine on May 6, 1896, at Quantico, Va., over the Potomac River.



THE QUARTER-SIZE MODEL FLYING OVER THE POTOMAC RIVER ON AUGUST 8,
1903.

This machine was built in 1900-1901, principally to test certain features of balancing, etc., for the large machine, and flights were first made with this model as early as June, 1901.

Attempts have been made to credit Da Vinci with the anticipation of the modern aeroplane, but there is nothing in his essay which can justify this claim. He made a study of the flight of birds, but his inferences were not correct in some important respects, and while we may give him credit for scientific method, it is apparent that he "thought of" rather than "thought out" the problem of human flight. Langley does not appear to have been acquainted with Da Vinci's work, at least it is not quoted in any of his writings that I have consulted, and in the article in the ninth edition of the *Encyclopedia Britannica*, which is given among his references, there is no mention of Da Vinci's investigations, but these are briefly noted in the eleventh edition (article on "Flight and Flying").

Claims have been made for many experimenters and investigators, as having made flights with small machines, but definite data have rarely been furnished, and it is probable that Langley is justified in his claim that until the experiments in May, 1896—to be later described—no true flight of a heavier-than-air machine had been made.

Machines based on the principle that Da Vinci discussed have been built and operated by several investigators. These have been mostly "gliders," enabling the person to make a slow, inclined descent from a high point, but not conferring the power of rising from the ground or alighting at a given place at a considerable distance from the starting point. A glider of this type was constructed by Otto Lilienthal, and operated many times in the year 1896. He was killed by the upsetting of his machine in a gust. Percy Pilcher made many such flights in 1899, but also lost his life in an accident. Octave Chanute, however, made over a thousand flights without injury to himself. These operators sometimes made their flight by running the machine, or having it pulled, against the wind and thus rising from the ground much the same way as a kite is flown. It is obvious, however, that these machines do not solve the problem of flying in its important practical applications. It is also obvious that modern flying machines, whether the dirigible balloon or the aeroplane, do not act wholly on the principles of flight by the bird or insect.

It is interesting to note that in animals the ratio of wing area to weight diminishes as the weight increases. Thus, according to the *Encyclopedia Britannica*, the wing area of the dragon fly is, in proportion to its weight, nearly 25 times that of the pigeon.

Langley began his investigations in 1887 at the Allegheny Observatory. At that time he was not aware that any other investigator had accomplished anything along the lines that he was working, but he subsequently found out that A. Pénaud, an ingenious French mechanic, had made in 1872, a machine about 20 inches long resembling some of the simpler modern aeroplanes, using twisted rubber as a motive power. He had described this in a journal called

L'Aéronaute. No copy of this journal is accessible to me, but the details of Pénaud's machine, with pictures, are given in the memoir quoted below. Pénaud stated that he had obtained a flight of 60 meters during 13 seconds. Langley was never able to obtain such results, but states that twisted rubber has a very high potential, being much more efficient than any steel spring he tried.

From the start Langley proceeded in a truly scientific manner, studying the mathematics and physics of the problem preliminary to construction of apparatus. His results are set forth in two publications, *The Internal Work of the Wind* and *Experiments in Aerodynamics*. He discovered that the law laid down by Newton, and accepted by most mathematicians and physicists—namely, that atmospheric resistance to inclined surfaces is proportionate to the square of the sine of the angle of inclination, is not founded in fact, the resistance being really proportionate to the angle directly. The interesting story of the invention of the practical aeroplane is to be found in the ponderous quarto of over 300 pages, entitled *The Langley Memoir on Mechanical Flight*, published by the Smithsonian Institution, and consisting of two papers, one mostly by Langley himself, the other by his faithful and efficient assistant, Charles M. Manly. It is from this publication that I have drawn most of the material for this essay.

Notwithstanding that the problem of flight had engaged human attention for many centuries, and had attracted all classes of persons, ranging from such a profound genius as Da Vinci to mere cranks and dreamers, yet when Langley took up the matter there were but few data available, and there was almost no one disposed to give him encouragement, tangible or sentimental. Distinguished scientists deprecated investigations into the subject. As late as 1900 a prominent astronomer and mathematician declared that it would be impossible to construct a machine capable of sustaining the weight of the largest known birds, not knowing that two of Langley's machines had already accomplished more than this. "The truly blind are those who will not see."

After several years' assiduous labor he was able to announce that it is possible to give such velocity to inclined surfaces that bodies indefinitely heavier than air could be driven through it with great velocity. As a concrete instance he states that a plane surface, 76.2 centimeters by 12.2 centimeters (about 1 square foot) weighing 500 grams, could be driven through air in absolutely horizontal flight at the rate of 20 meters per second with 0.01 horsepower. This is equivalent to a weight of 200 pounds driven through air by 1 horsepower at 40 miles per hour.

Following up this conclusion, a number of machines were constructed and tried out, some of them, of course, quite small, others of

considerable size. For all the machines he made Langley coined the word "Aerodrome," from two Greek words meaning "air runner." This word is now often used as the name for the shed in which the flying machine is stored.

In passing from very small machines in which twisted rubber or steel springs can be used, which are mere toys, to large machines which can make reasonably long flights, the question of motor became of great importance. Questions of stability, both lateral and longitudinal, also required answer. I will not enter into a consideration of stability problems. They were most carefully investigated by Langley, and involved mathematical as well as mechanical methods. It is now well known that the stability of aeroplanes has been satisfactorily attained.

When Langley began his experiments the only motor that seemed to offer practical application was the steam engine. This had been for a long while the only one applicable to a moving object, as is indicated by its extensive use in both land and water transportation. The steam engine is heavy, and also requires fuel and water, so that the total weight is considerable. In the ordinary uses of it in land transportation this is not a very serious matter, for the locomotive draws best when it presses strongly on the rails, and even in water transportation the weight of engine, fuel, and water are probably of less importance than the space they occupy. Langley, in 1891, canvassed the portable motors then known. These were, in addition to steam, compressed air, liquid carbon dioxide, electric batteries, gunpowder, and the internal-combustion engine. The last-named, which is now the only motor used in flying machines, was at that time but little developed, and was rejected, as were all the others except the steam engine. The requirements were that the apparatus should be light, capable of developing steam rapidly and at considerable pressure, and using a fuel of high heating efficiency. Water-tube boilers were alone suitable, alcohol or gasoline as the fuel. Oscillating engines were used at first. Many experiments were made with boilers and with burners, and much difficulty was experienced in getting and maintaining sufficient pressure. Langley's accounts of the failures and disappointments make painful reading, but space does not permit a summary of these matters, especially as the steam engine has ceased to be important in the field with which we are now concerned.

After many months of weary working it was finally thought to be possible to secure a flight in the open air, and preparations were made for this. The story of the failures, disasters, and disappointments that preceded the actual flight—told with much vividness in the "Memoir"—is a striking instance of the will power and self-

reliance of the inventor, and of his possessing to a high degree that characteristic of genius, "the infinite capacity of taking trouble."

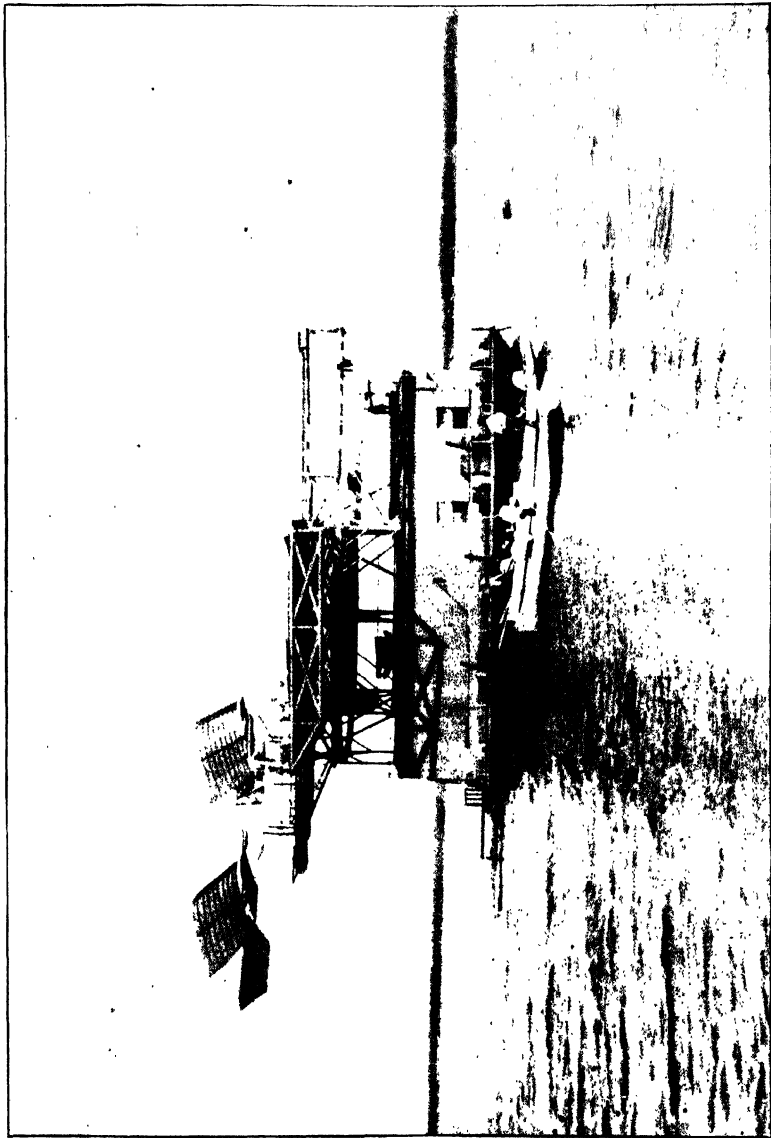
After succeeding in the construction of a power-driven flying machine, two problems were presented in connection with open-air trials; a suitable locality and a method of launching. It was decided that it would be safest to launch the machine over water, as in case of a fall it would be not seriously damaged and be readily recovered. It was, of course, also advisable that the location should not be far from Washington, at which place the construction was being carried on, and should not be in a populated district. The spot chosen was a small island in the Potomac River, about 30 miles below Washington.

For launching the machine a sort of house boat was built by putting a frame room on a scow, and on the roof of this a horizontal track with releasing apparatus. The room served for storing the machine and was fitted with apparatus for repair work.

In the later part of 1893 an aerodrome, designated as No. 4, was taken to the trial ground, but though eight trips were made for trials, none was successful, and the year closed without any demonstration of the capacity of the machine. The year 1894 was also passed without any successful flight, although a few short movements had been secured, and the machine seemed to be less erratic and the power was shown to be sufficient for the work. Little better results were obtained during 1895, but much information as to the defects of construction were obtained, so that with the opening of the following year this problem was much nearer solution, in fact, was solved.

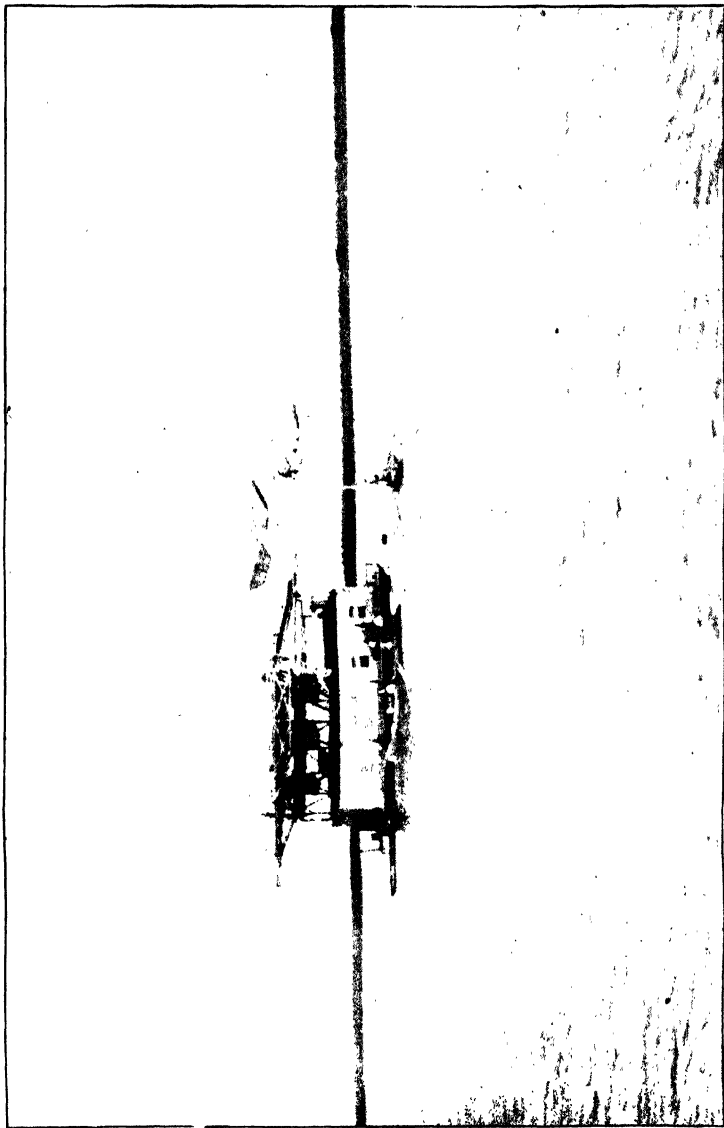
In the early part of 1896 two aerodromes, 5 and 6, were available, and on May 6 of that year, Langley with A. Graham Bell and several assistants were at the trial ground. The wind was so high during the morning that no attempt at flight was made, but at 1 p. m. it had become much less active, and at 1.10, aerodrome No. 6 was launched, but owing to some entanglement with the launching apparatus, it settled directly into the water. Aerodrome 5 was then tried. At 3.05 it was launched with a steam pressure of 150 pounds, and started directly into the gentle breeze that was blowing.

The height of the launching track above the water was about 20 feet; the machine first descended about 3 feet, but immediately began to rise until the midrib made an angle of about 10° with the horizontal, and maintained this mostly through the entire flight. After leaving the boat, it circled to the right and moved with great steadiness, making a spiral path of two complete turns and part of a third. During the first two turns the apparatus was constantly ascending, and at the end of the second turn had reached a height estimated at over 75 feet. The power then began to give out and the machine slowly descended, striking the water in approximation to a



SIDE VIEW OF THE FULL-SIZE MAN-CARRYING AERODROME ON THE HOUSEBOAT JUST BEFORE THE TRIAL OF
OCTOBER 7, 1903.

This shows the track on which the machine was propelled by springs and shot off into the air.



THE OCTOBER 7, 1903, TRIAL OF THE LARGE MACHINE CARRYING AN AVIATOR.

The front guy caught in its support on the launching car and was bent backward, causing the front end of the machine to be jerked violently downward before it was actually in free flight.

"nose dive," having been in the air 80 seconds and traveled about 3,300 feet, which would mean a rate of about 20 miles per hour. The machine was recovered at once, and being found not injured, a second trial was made, with somewhat similar result, making three turns at a height of about 60 feet, during 91 seconds, over a path estimated as carefully as possible at 2,300 feet. Several photographs were taken during these flights.

These flights, of course, meant much to the patient inventor and his friends. For the first time in the history of the world a heavier-than-air machine had actually flown through the air and preserved its equilibrium without the aid of a guiding intelligence. Moreover, a second trial had been made, thus showing that the first was no mere accident.

It seems somewhat curious that these striking results were not immediately followed up. No explanation of the suspension of the experiments is given in the "Memoir," except to say that the inventor left for Europe, intending to be away until fall. Instructions were given to the mechanics to remedy certain small defects in the machines.

On November 27 a trial was made of aerodome 6, but owing to the breaking of a pin, the trial was a failure. In the afternoon of the next day, a successful flight was made, the machine going in a curved path of about three-quarters of a mile in 105 seconds, a rate of about 30 miles per hour. "*Finis coronat opus.*"

Obviously the success of the aerodromes led to the thought of the construction of a man-carrying machine. Langley hesitated on account of the many duties in connection with his official relations with the Smithsonian Institution, yet the longing to take the final step was too attractive to his scientific mind and soon took possession of him. Ten years had been passed in laborious experiment, full of disheartening difficulties, and he thoroughly realized that the construction of a machine large enough to carry a man would be a mighty labor, but his spirit was no flickering flame like that of light straw, but determined and devoted to the object of science—the discovery of truth.

In undertaking the construction of a large aerodrome, Langley was much influenced by President McKinley, who had become impressed with the value of the instrument in war. It will not be necessary to set forth here the official procedures which led up to the work, but merely to state that in the latter part of 1898, an appropriation of \$50,000 was made for the purpose through the Board of Ordnance and Fortification.

Langley had always recognized that one of the most important problems in a flying machine is the motor, which should be light, powerful and capable of maintaining its action for a long time on

a small volume of fuel and other supplies (such as water). The internal-combustion engine, then coming into notice, was obviously the most promising form, but as he was not familiar with this apparatus, he deemed it proper to delay definite action until a satisfactory engine could be secured. After much searching, a contract was placed on December 28, 1898, for a 12 horsepower engine to weigh not more than 100 pounds, and the construction of an aerodrome for use with this engine was at once begun. Notwithstanding the amount of research that had been given to the mathematics and physics of flight to heavier-than-air machines, it was felt that the new problem required much more investigation and research, and of course, a new element entered into it, namely that of preventing the injury or death of the operator.

The great complexity of the problem induced Langley to seek the services of a mechanical engineer, and on the recommendation of Professor Thurston, Mr. Charles M. Manly was appointed, and proved to be a most efficient and faithful worker. It was hoped that the engine could be obtained and the frame-work of the new aerodrome completed by the early part of 1899, but this was not to be. The engine builder though he exerted himself to the utmost and, indeed, lost much money in his effort, was not able to produce an engine which would give anything like the desired horsepower within the allowable weight. Another series of disheartening failures and disasters followed. As a preliminary, an aerodrome one-quarter size of the proposed man-carrying one was constructed and trial flights made with success, but this small machine could not, of course, carry an operator. In addition to the problem of the construction of the large machine, a new apparatus for launching was devised and a new location, about 40 miles below Washington on the Potomac was selected. It became necessary here to have a tug-boat and housing for the workmen, who could not come and go from Washington every day.

Nowadays, when aeroplanes are among familiar objects and almost everyone has seen them start and land, it seems that a serious mistake was made in the elaborate launching apparatus, and in the principle of launching over water, but it is easy to be wise after the event, and we must always keep in mind that Langley was working in a field in which there was no definite guidance, save his own studies and experiments.

The engine builder having finally given up the problem, efforts were made to get some European builder to manufacture the apparatus, Europe being, it was thought at that time, ahead of America in the application of the internal combustion motor. No one could be found willing to undertake the contract. Under these circumstances, Mr. Manly undertook the work. He obtained the parts of

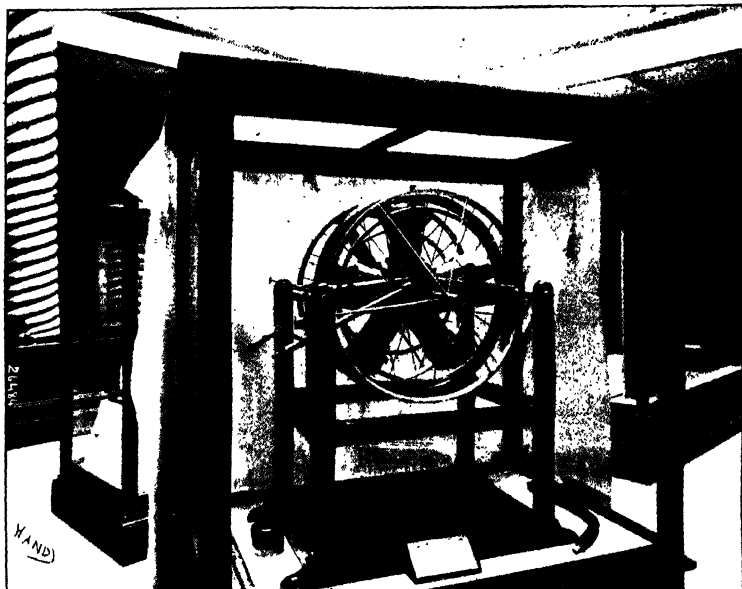


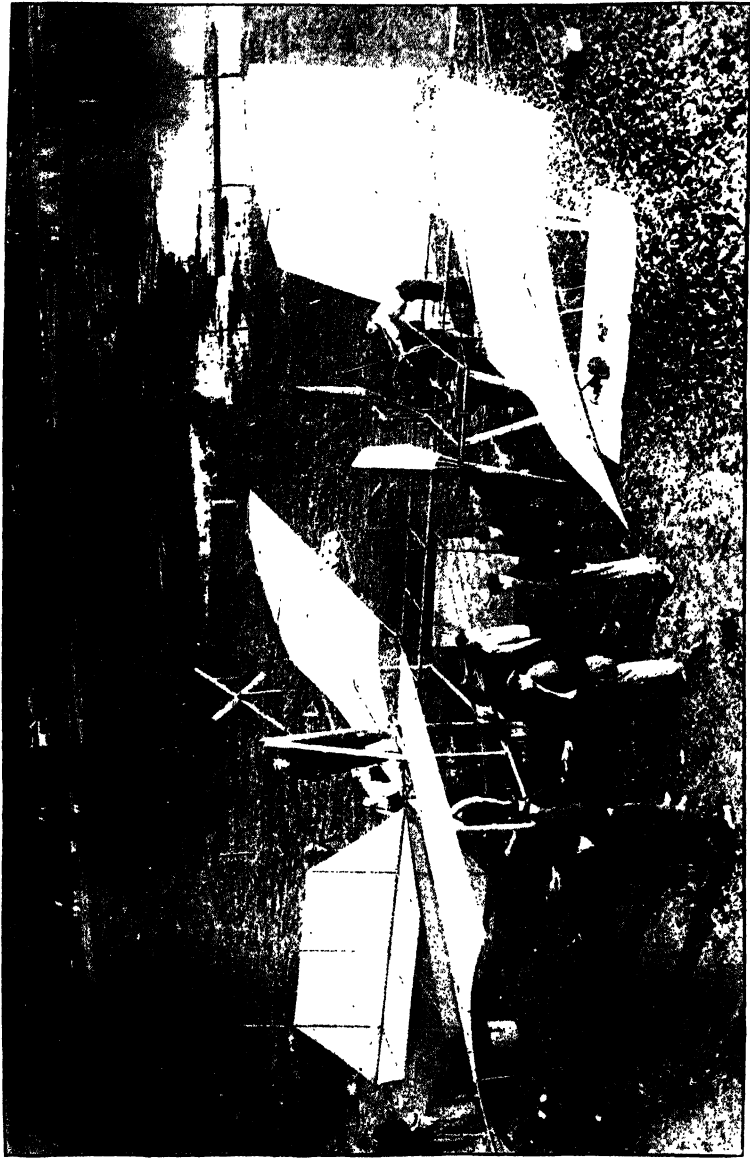
FIG. 1.—FIVE-CYLINDER GASOLINE ENGINE OF 52 HORSEPOWER AT 950 REVOLUTIONS PER MINUTE.

This engine, which was used in the full-size machine, was built in the Smithsonian shops under Prof. Langley's direction and is now on exhibit in the National Museum.



FIG. 2.—THE LARGE LANGLEY FLYING MACHINE AS AT PRESENT ON EXHIBITION IN THE UNITED STATES NATIONAL MUSEUM.

Near it (directly above the John Bull engine) is the quarter-sized model.



ATTACHING WINGS AND PONTOONS TO THE LARGE LANGLEY MACHINE IN PREPARATION FOR ITS FLIGHT OF MAY 28, 1914, AT HAMMONDSPORT, N. Y.

the engine which the American builder had made and in the latter part of 1900 began his work. He was able in September of that year, to construct an engine weighing 108 pounds which gave on the Prony brake, 18.5 horsepower at 750 revolutions per minute. The cylinders were, however, without water jackets, being cooled with wet cloths, which, of course, would permit only short runs.

The details of the development of the engine, of the difficulties with sparking apparatus, carburetors, pistons, packing, lubrication, and all the other vexations that go to make up what are collectively known as "engine troubles" are described vividly and fully in the "Memoir," but space does not permit of even a brief summary here. Not the least of the troubles in the history of the affair was the weather, which was very often exceedingly unfavorable.

Finally, however, an engine was built which recorded 52.4 horsepower at the average speed of 950 revolutions per minute, with an approximate weight for the engine proper of 124.17 pounds, or, including the improved water jackets, fly-wheels, spark coil, batteries, etc., complete, a total of 187.47 pounds.

Mr. Manly volunteered to be the operator for the first trip of the aerodrome. His chief consented to this, though with much reluctance. Every possible precaution was taken to prevent serious accident, and on October 7, 1903, about 16 years after the work had begun at the Allegheny observatory, the machine was launched with Manly in the aviator's chair. It was a little after noon that the machine glided down the launching track. The operator soon felt the sensation of being free in the air, when he noted that he was plunging downward at a very sharp angle, and instinctively grasped the wheel which controlled the Pénaud tail, intending to throw it up so as to depress the rear, but the effort failed, the machine crashed into the water and it was with some difficulty that the operator was saved from drowning. The machine was recovered from the water and certain slight defects discovered as the cause of the mishap. Arrangements were made to remedy these and the party returned to Washington, after giving out a brief statement to the press. Fortunately, an excellent photograph had been secured just as the machine left the launching platform, and also another taken close to the wings, from which certain important facts can be easily established.

Examination showed that the machine was not seriously injured and it was decided to make another attempt, but for convenience a spot much nearer to Washington was chosen. On account of the lateness of the season, favorable weather was unusual, and it was December 8 before conditions were satisfactory. Some delay occurred in getting the machine taken to the place of trial, and dark-

ness was setting in and the wind had become strong and gusty. Nevertheless, Manly took his station at the wheel, and the machine was launched, but something happened that has never been clearly determined. The machine shot upward and then fell into the water, entangling the pilot, who again narrowly escaped drowning. Owing to the darkness the official photographer got no pictures, as his shutters were set to too high speed, but a representative of the Washington Star secured a small photograph, which on enlargement showed some points of importance, principally that the accident was due to the rudder becoming entangled in the launching track, owing to the breakage of some part of the mechanism by which it was connected to the main frame.

The situation became very distressing. The inventor felt that he could not ask for further funds from the Smithsonian Institution, and the Board of Ordnance and Fortification having been severely criticized on the floor of Congress for its original allotment for the work, it was deemed inexpedient to ask for further aid, as it might incur a curtailment of the funds placed at the disposal of the board.

In 1904 Manly made efforts to secure assistance from wealthy Americans, but all whom he approached declined to aid unless arrangements would be made for later commercialization. Langley had years before tempting offers of this character, but had always declined and he again declined to accept these conditions. In 1906 he died. Had he been spared a few years he would have seen all his hopes realized as the sequel shows.

THE SEQUEL.¹

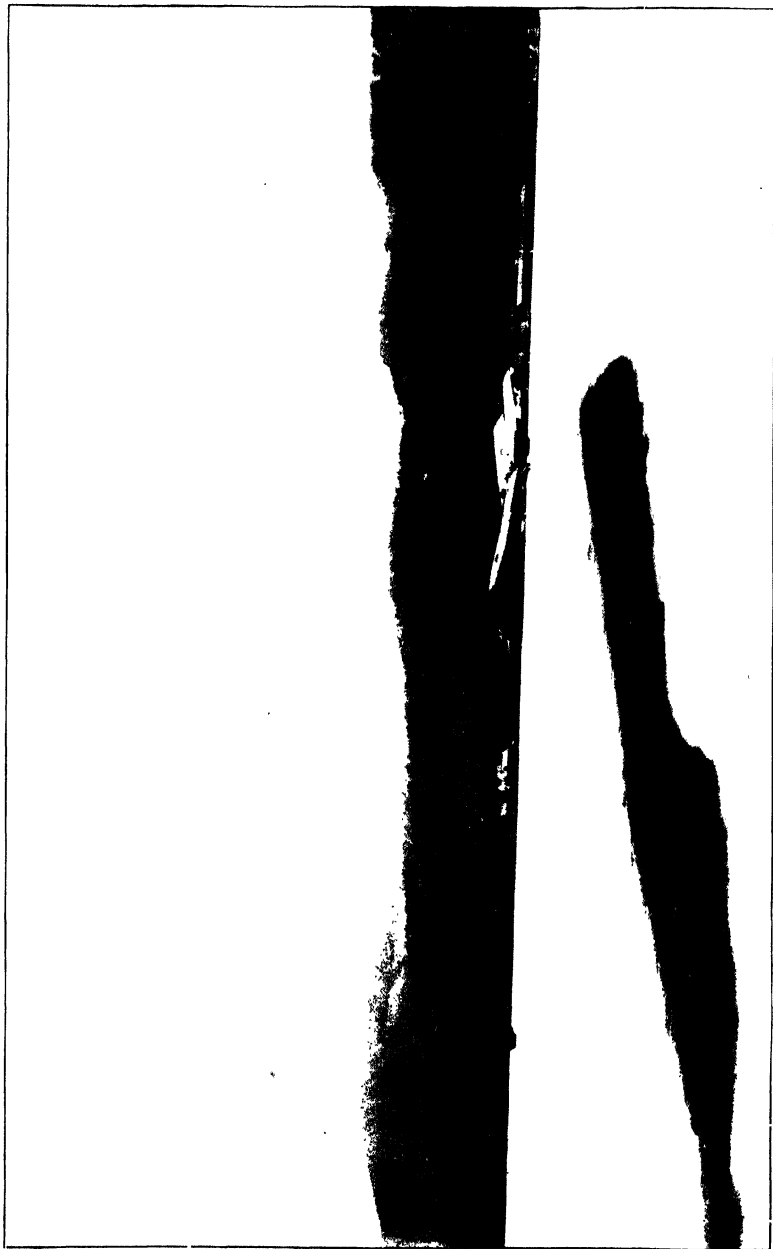
May 6 is celebrated in Washington, informally, as Langley Day, being the anniversary of the first satisfactory flight of a heavier-than-air machine. In March, 1914, Glenn H. Curtiss, aviator and inventor, was invited to take part in the ceremonies on the next occasion. He replied: "I would like to put the Langley aerodome itself in the air." Secretary Walcott, of the Smithsonian Institution, at once granted the request, and in April the machine was taken to the Curtiss plant on Lake Keuka, Hammondsport, N. Y. It was overhauled but not materially changed, except to put hydroplane floats on it. On May 28, 1914, two months before the great war broke out, and 18 years after the successful flight of the first aerodrome, the craft of 1903 was lifted into the water with Curtiss at the wheel, and many eager camera men waiting with loaded weapons. Pointed somewhat across the wind, the machine automatically headed into it, rose in level poise, soared steadily for 150 feet and landed softly in the water. After a few more flights, the engine and propellers were

¹ For most of the data of this paragraph I am indebted to an article by Dr. A. F. Zahm, in *Ann. Rep. Smithsonian Inst.* for 1914.



"PLANING" OVER LAKE KEUKA, AT HAMMONDSPORT, N. Y.

With Glenn H. Curtiss in the aviator's seat, the machine was photographed just as it was rising from the water.



VIEW OF FLIGHT OF JUNE 2, 1914, OVER LAKE KEUKA, AT HAMMONDSPORT, N. Y.
Piloted by Curtiss, and with 300 pounds of pontoons added, satisfactory flights were made with the original engine and machine.

replaced by an 80-horsepower Curtiss motor, and direct-connected tractor propellers. In the absence of Mr. Curtiss, a pupil of his school, Mr. Doherty, took the wheel. Beginning September 17, a number of flights were made, which demonstrated that the general principles of Langley's construction were perfectly sound, and to him must be given the credit of being the pioneer in practical aviation, and of having, by his devotion and persistence, helped to bring into a field of scientific inquiry what had been previously almost entirely in the possession of visionaries or charlatans. In this connection we must not overlook the services of Manly, to whom is due largely the construction of a satisfactory gasoline engine, then first used in an aeroplane, and who twice risked his life in trials of the large machine.

The following paragraphs are copied verbatim from the article indicated in the footnote on page 166:

Dr. Langley's aerotechnic work may be briefly summarized as follows:

1. His aerodynamic experiments, some published and some as yet unpublished, were complete enough to form a basis for practical pioneer aviation.
2. He built and launched, in 1896, the first steam model aeroplane capable of prolonged free flight and possessing good inherent stability.
3. He built the first internal-combustion motor suitable for a practical man-carrying aeroplane.
4. He developed and successfully launched the first gasoline model aeroplane capable of sustained free flight.
5. He developed and built the first man-carrying aeroplane capable of sustained free flight.

TWENTIETH CENTURY PHYSICS.¹

By R. A. MILLIKAN.

My position to-night is somewhat reminiscent of a story which my father used to be fond of telling of a Scotch preacher who thought that all of the italicized words in the Holy Writ were meant to be emphasized, and so he read "And Abraham said unto his servants, saddle me an ass, and they saddled *him*." When one of his parishioners expostulated with him and told him that he didn't think that was really what was meant, being a Scotchman, the preacher kept his own opinion, but being endowed also with a certain amount of worldly wisdom, he said he would change it, and so the next time he read, "And Abraham said unto his servant, saddle *me* an ass, and they *saddled* him."

The point of the story is that it doesn't make any difference where the emphasis is placed, the situation remains entirely unchanged. I am, however, really glad to be saddled tonight, because I should like to do a little bit, if I can, towards bridging the chasm which we have foolishly—I had almost said idiotically—allowed to grow up between the physicist and the applied physicist, who commonly is called an engineer. The chemists have been very much more sensible; they have not split up into two groups, called chemists and applied chemists, and there is absolutely no more reason why we should have done so, for obviously the physicist is merely the vanguard in the army of engineers, the scout, the explorer, who is given the task of trying to open up new paths for human progress, of prospecting for new leads to nature's gold, and it is just as important that the engineer know where the scout is and what he is doing as it is that the scout know where the army is which is behind and which supports him.

If you have any respect for my subject or any respect for me you will not expect me to outline in the space of one brief hour the work of modern physics. It is utterly impossible to do, and I can say that without affecting an inordinate egotism. I had the good fortune to

¹ A lecture delivered at the Fifth Midwinter Convention of the American Institute of Electrical Engineers, New York, Feb. 15, 1917. Copyright 1917, by A. I. E. E. Reprinted by permission from the Proceedings of the American Institute of Electrical Engineers, September, 1917.

listen a little while ago to a series of lectures by our honored ex-President, Mr. Taft, on "The Executive Power," and he said in those lectures that his friend, Mr. Roosevelt, had somewhere classified the Presidents of the United States into two groups—the first, the group that had interpreted the executive power broadly and exercised it largely, and the second, the group that had interpreted it narrowly and exercised it sparingly, and, said Mr. Taft, "Mr. Roosevelt began the first group with Lincoln and closed it with himself, and he began the second group with Buchanan and closed it with myself." Then, with his inimitable chuckle, Mr. Taft said, "That reminds me of a story about a little boy who came home from school and said, 'Papa, did you know I was the brightest student in the class?' His father replied, 'No, I didn't know it. When did the teacher tell you so?' The boy answered, 'The teacher didn't tell me so at all, I just noticed it myself.'"

If I appear at all, in what I say, to have just noticed it myself, I beg of you at any rate to believe me that the appreciation is an appreciation of the subject, of the method which it uses, of the spirit which underlies it, and of the results which have actually flowed from it, and not an appreciation of any individual or group of individuals.

The spirit of modern science is something relatively new in the world's history, and I want, as an introduction to the main address, to give an analysis of what it is. I want to take you up in an airplane which flies in time rather than in space, and to look down with you upon the high peaks which distinguish the centuries, and let you and me see together what is the distinguishing characteristics of this century in which we live. I think there will be no question at all, if you get far enough out of it so that you can see the woods without having your vision clouded by the proximity of the trees, that the thing which is characteristic of our modern civilization is the spirit of scientific research—a spirit which first grew up in the subject of physics and has spread from it to all the other subjects of modern scientific inquiry.

That spirit has three elements. The first is a philosophy, the second is a method, and the third is a faith. Look first at the philosophy. I say that is new for the reason that all primitive peoples, and many that are not primitive, have held a philosophy that is both animistic and fatalistic. Every phenomenon which is at all unusual, or for any reason not immediately intelligible, used to be attributed to the direct action of some invisible personal being. Witness the peopling of the woods and streams with spirits by the Greeks, the miracles and possession by demons of the Jews, the witchcraft manias of our own Puritan forefathers, only two or three hundred years ago.

Now, that a supine fatalism results from such a philosophy is to be expected, for according to it everything that happens is the will of the gods, or the will of some more powerful beings than ourselves. And so, in all the ancient world, and in much of the modern also, three blind fates sit down in dark and deep inferno and weave out the fates of men. Man himself is not a vital agent in the march of things, he is only a speck, an atom which is hurled hither and thither in the play of mysterious, titanic, uncontrollable forces.

Now, the philosophy of physics, a philosophy which was held at first timidly, always tentatively, always as a mere working hypothesis, but yet held with ever-increasing conviction from the time of Galileo, when the experimental method may be said to have had its beginnings, clear up to the present time, is the exact antithesis of the above. Stated in its most sweeping form it holds that the universe is ultimately rationally intelligible, no matter how far from a complete comprehension of it we may now be, or indeed may ever come to be. It believes in the absolute uniformity of nature. It views the world as a mechanism, every part and every movement of which fits in some definite, invariable way, into the other parts and the other movements; and it sets itself the inspiring task of studying every phenomenon in the confident hope that the connections between it and other phenomena can ultimately be found. It will have naught of caprice in nature. It looks askance at mysticism in all its forms whether put forth by Dionysius in Greece in 300 B. C. or by the devotees of Bergson in Paris in 1915. That is the spirit, the attitude, the working hypothesis of all modern science, and let me say that this philosophy is in no sense materialistic, because good, and mind, and soul, and moral values, which is only another word for God, these things are all here just as truly as are any physical objects, and with that kind of a creed they must simply be inside and not outside of this matchless mechanism.

Second, as to the method of science, it is a method practically unknown to the ancient world, for that world was essentially subjective in all its thinking and built up its views of things largely by introspection. The scientific method, on the other hand, is a method which is completely objective. It is the method of the working hypothesis which is ready for the discard the very minute it fails to work. It is the method which believes in a minute, careful, wholly dispassionate analysis of a situation; and any physicist or engineer who allows the least trace of prejudice or preconception to enter into his study of a given problem violates the most sacred duty of his profession. This present cataclysm which has set the world back a thousand years in so many ways, has shown us the pitiful spectacle of scientists who have forgotten completely the scientific

method, and have been controlled simply by prejudice and by preconception. This is no reflection on the scientific method; it merely means that these men have not been able to carry over the methods they use in their science into all the departments of their thinking. The world has been controlled by prejudice and emotionalism so long that reversions still occur, but the fact that these reversions occur *after all* does not discredit the scientist, nor make him disbelieve in his method. Why? Simply because that method has worked, it is working to-day, and its promise of working to-morrow is larger than it has ever been before in the world's history.

Do you realize that within the lifetime of men now living, within a hundred years, or 130 years at most, all the external conditions under which man lives his life on this earth have been more completely revolutionized than during all the ages of recorded history which preceded? My great-grandfather lived essentially the same kind of a life, so far as external conditions were concerned, as did his Assyrian prototype 6,000 years ago. He went as far as his own legs or the legs of his horse could carry him. He dug his ditch, he mowed his hay, he did all the operations of his industrial life, with the power of his own two arms, or the power of his wife's two arms, with an occasional lift from his horse or his ox. He carried a dried potato in his pocket to keep off rheumatism, and he worshipped his God in almost the same superstitious way. It was only in the beginning of the nineteenth century that the great discovery of the ages began to be borne in upon the consciousness of mankind through the work of a few patient, indefatigable men who had caught the spirit which Galileo perhaps first notably embodied, and passed on to Newton, to Franklin, to Faraday, to Maxwell, and to the other great architects of the modern scientific world in which we live—the discovery that man is not a pawn in a game played by higher powers; that his external, as well as his internal destiny is in his own hands.

You may prefer to have me call that not a discovery but a faith. Very well. It is the faith of the scientist, and it is a faith which he will tell you has been justified by works. Take just this one illustration, suggested by the opening remarks of your president. In the mystical, fatalistic ages which preceded, electricity was simply the agent of inscrutable Providence; it was Elijah's fire from Heaven sent down to consume the enemies of Jehovah; or it was Jove's thunderbolt hurled by an angry God; and it was just as impious to study so direct a manifestation of God's power in the world as it would be for a child to study the strap with which he is being punished, or the mental attributes of the father who is behind the strap. It was only 150 years ago that Franklin sent up his famous kite, and showed that these thunderbolts were identical with the sparks which he could draw on a winter's night from his cat's back. Then, 30 years

after that Volta found that he could manufacture these same thunderbolts artificially by dipping dissimilar metals into an acid. And 30 years farther along Oersted found that those same thunderbolts when tamed and running noiselessly along a wire would deflect a magnet, and with that discovery the electric battery was born, and the erstwhile blustering thunderbolts were set the inglorious task of ringing house bells, primarily for the convenience of womankind. Then 10 years later Faraday found that all he had to do to obtain a current was to move a wire across the pole of a magnet, and in that discovery the dynamo was born, and our modern electrical age, with its electric transmission of power, its electric lighting, its electric telephoning, electric toasting, electric foot warming, electric milking—all that is an immediate and inevitable consequence of that discovery—a discovery which grew out of the faith of a few physicists that the most mysterious, most capricious and the most terrible of natural phenomena is capable of a rational explanation and ultimately amenable to human control.

In that statement I have revealed the taproot of the civilization of the nineteenth century. Add to it a bit to cover the harnessing of steam, and the development of the principle of the conservation of energy, and you have an epitome of the progress of the century just passed. It all grew out of the application of an extraordinarily small number of discoveries as to the way in which nature works.

And at the end of the nineteenth century there were many of us physicists and engineers who thought that all the great discoveries had been made. It was a common statement that this was so. I heard it publicly made in 1894; and yet within a year of that time I happened to be present in Berlin at the meeting of the physical society at which Roentgen showed his first photographs, and since that time we have had a whole new world, the very existence of which was undreamed of before, opened up to our astonished eyes. We have found a world of electrons which underlies the world of atoms and molecules with which we had been familiar, and the discoveries in that world have poured in so rapidly within the last twenty years that there are no two decades in human history that compare at all with them in the rapidity of the advance. And these discoveries have been made too for the most part by groups of men interested merely in finding out how nature works. They have been made almost exclusively by college professors; and for 10 years they remained the exclusive property of these professors.

But what has happened in the last 10 years? The industrial world has fallen over itself in the endeavor to get hold of these advances, and by their aid it has increased tenfold the power of the telephone, it has obtained four or five times as much light as we got a few years ago out of a given amount of electrical power it has de-

veloped new kinds of transformers the existence of which was never dreamed of before—all these things are coming now, it is not in the distant future, that we are going to find the applications; we have found in the last five years a great quantity of them, and how many more are going to come, no man can tell.

And yet we must not focus our attention too intently upon the utility of a discovery. Did you ever hear the story of what happened when Faraday was making before the Royal Society in 1831 that experiment to which your chairman referred? He performed his experiment, and then explained it. It was simple, it did not look particularly interesting. One saw only a deflection of a needle. And some woman in the audience said, "But Prof. Faraday, of what use is it?" His reply was, "Madam, will you tell me of what use is a new born babe?"—and what a reply it was! Infinite possibilities—possibilities which may indeed not be realized, but at any rate something altogether new. Faraday did not care of what immediate use that new thing was, for he was one of the great souls who had caught the spirit of Galileo. He knew that human progress depends primarily upon the growth of the human mind, the ability of man to get hold of nature. The utilities might come, they always do come, but they generally crop out as by-products, and the man who has got his mind fixed merely on utilities is simply the man who kills the hen to get the golden egg. I have just as much respect for utilities as you or anybody has; I believe that nothing is worth while except as it contributes in the end to human progress, but the difficulty is that you can not tell, nor can I nor anybody else tell, what is going to contribute to human progress. The thing that is important is that the human mind should grow. That is the *sine qua non* of progress. At the capitol in Harrisburgh there is a picture by Sir Edwin Abbey, which is entitled, "Wisdom, or the Spirit of Science." It consists of a female veiled figure with the forked lightnings in one hand, and in the other the owl and the serpent, the symbols of mystery; and beneath is the inscription:

"I am what is, what hath been and what shall be.

My veil has been disclosed by none.

What I have brought forth is this: The sun is born."

It is to lighten man's understanding, to illuminate his path through life, and not merely to make it easy, that science exists. Hence, if you ask me what are the utilities of the particular category of discoveries which I am going to run over here very rapidly, I may be able to tell you of a good many of them, but I shall not try to catalogue them all, because that is not where our immediate interest lies. It is "where there is no vision" that "the people perish."

Finally, before launching upon the sea of recent discovery, I wish to make one more remark about the method of science—namely,

this: The progress of science is almost never by the process of revolution. You see a great deal in your newspaper headings about revolutionary discoveries. They almost never happen. Thus when the atom was found not to be an ultimate but a divisible thing, there was no revolution, there was not a single law that had to be given up. We had simply opened up a new field, tapped a new lead, found an unexplored region, a sub-atomic region, and all that was above it remained just exactly as it had been, and no chemist had any occasion to be disturbed, for the chemists' laws were just as precise as they had been before. Sometimes we do indeed find that we have generalized too far, and that some law which we had supposed to be of universal application is limited in its scope, but this does not alter the fact that the growth of science is in general by a process of accretion, almost never by that of revolution. Once in a while we have something revolutionary but not often.

Let me now run over a list of 10 discoveries which I will call the 10 most important advances of the last 20 years. I will not keep you long upon them; I will just touch upon them, because I could spend the whole evening on any one of them.

We may aptly characterize the physics of the last 20 years as the physics of atomism, and the first discovery on my list of 10 advances is the recent verification of the adumbrations of the Greeks regarding the atomic and the kinetic theories—the proof that, as Democritus had imagined 500 B. C., this world does indeed consist, in every part of it, of matter which is in violent motion.

Up to within six years there were not a few distinguished scientists who withheld their allegiance even from these atomic and kinetic theories of matter. The most illustrious of them was Prof. Wilhelm Ostwald, but in the preface to a new edition of his *Outlines of Chemistry* he now says frankly:

I am convinced that we have recently become possessed of experimental evidence of the discrete or grained nature of matter for which the atomic hypothesis sought in vain for hundreds and thousands of years. The isolation and counting of gaseous ions on the one hand * * * and on the other the agreement of the Brownian movements with the kinetic hypothesis * * * justify the most cautious scientist in now speaking of the experimental proof of the atomic theory of matter. The atomic hypothesis is thus raised to the position of scientifically well-founded theory.

I think you all know what the Brownian movements are, but I wish especially to call attention to the fact that this advance was made not by a practical man, but by a man who never did any experimental work in his life, Einstein, a mathematician, a man who was capable of analyzing a theory and predicting results, and the experimentalists have checked those results. The results consist in predicting how far a given particle that you can see in an ultra

microscope will drift in a given time, and our own experiments have checked this prediction to within one-half per cent. It is that sort of evidence that has convinced Ostwald of the correctness of the kinetic and the atomic theories.

The second advance is the proof of the divisibility of the atom, a proof which grew out of the discovery of X-rays. Let me tell you how. If you have here two plates with an electric field between them, and nothing else but a monatomic gas like helium, then it is found that when the field is thrown on, the helium is perfectly stagnant, but when a beam of X-rays is shot between the plates some of the molecules become electrically charged and begin to jump, a part of them toward the upper plate and a part toward the lower plate, where their presence can be detected by an electrical measuring instrument. What does that show? It shows that the thing which we call an atom has electrical charges as its constituents; and the history of the last 20 years in physics has consisted pretty largely in determining what are the properties of these electrical constituents.

The third is the discovery of radio-activity, which occurred just a little after the discovery of X rays. And here again we found matter doing things we had never dreamed it was doing—viz., shooting off from itself both negatively and positively charged particles, the negatives with a speed which may approach close to the velocity of light, 186,000 miles per second, and positives with a speed of one-tenth of that, or 18,000 miles. The fact that such speeds could be imparted to projectiles of any kind was undreamed of 20 years ago.

The fourth discovery that I wish to mention is the discovery of the atomicity of electricity, the proof that the thing we call electricity is built up out of a definite number of specks of electricity, all exactly alike, and that what we call an electrical current consists simply in the journey along the conductor of these electrical specks, which we may call with perfect justice definite material bodies. Now, I can give you in just a word the proof of that statement. There are half a dozen ways in which it could be approached. I will mention the one with which I am most familiar, because it is the particular proof which we worked out at our laboratory. We took these plates with a field of 10,000 volts between them, with a little hole in the top plate, and we blew an oil spray above the top plate so as to get an electrically charged body just as small as we could, for we expected that the frictional process involved in blowing the spray would charge the drops, which it was found to do. We let one of these drops come into the space between the plates and then moved it up and down by an electrical field, throwing on the field as it came close to the bottom plate, and throwing it off as it approached the upper one, and so we kept that oil drop going up and down between the

plates, in the hope that it would capture some of the ions which we knew existed in the air, put there by radium or other agencies. The drop met our fullest expectations as a police officer, capturing ions frequently and signaling the fact of each capture to the observer by the change in its speed in the field. For the oil drop is an electrically charged body, and in a given field it moves with a definite speed. If, however, it captures an ion, its charge increases or decreases, and hence its speed increases or decreases. If the charges on ions are all alike, then we can only get one particular change in speed. If the charge that is already upon it, put there by the frictional process, is built up out of these same units, then the total speed which the field will impart must be an exact multiple of the change in speed which the capture of an ion produces. In other words, if electricity is atomic in structure, then in a given field it should be impossible to obtain any except a definite number of speeds which will make an arithmetical series—that is, will come up by steps, one, two, three, etc. That is exactly what we found to be the case. We have experimented with thousands of drops and scores of different substances, and they always work in exactly the predicted way. Both positively and negatively charged drops are found to act in quite the same way, showing that both positive and negative electrical charges are built up of specks of electricity. Further we can count the number of those specks (which we will call electrons) on a given drop, with the same certainty with which you can count the number of fingers that are before you now. And again since Rowland showed that an electrical current is nothing but a charge in motion, you have here the proof that the electrical current that goes through these lamps, for example, is nothing except the motion of a certain number of electrical specks through or over the filament of the lamp. Add to that J. J. Thomson's discovery made in 1881, that an electrical charge possesses inertia, the only distinguishing property of matter, and you have made it perfectly legitimate to say that an electrical current in a wire is a definite, material, granular something which is moving along that wire.

The fifth great discovery of modern physics is the bringing forward of evidence for the electrical origin of mass. I have just said that electricity is material. Can we turn it around, and say that all matter is electrical in origin? The last is not exactly the same as the first, and it needs evidence. When we have proved that an electrical charge possesses inertia or mass we have not shown that there is no inertia in matter which is not electrical in its origin. Now we have a certain amount of evidence upon this point and I wish to state what that evidence is.

We can measure the inertia of the negative electron and it is found to be $\frac{1}{1843}$ of the inertia of a hydrogen atom, but the positive

electron is never found with an inertia less than the inertia of a hydrogen atom. Let us consider the inertia of the negative. So long as it is moving slowly compared with the speed of light its inertia remains constant because the shape of its electromagnetic field is not appreciably distorted by its motion. But as soon as you imagine it to be moving with a speed which is close to the speed of light, that is with a speed which is nearly as great as the speed with which its own electromagnetic field can travel forward, then further change in speed will distort the field and hence change the inertia. In other words, the inertia of a charge ought to be a function of speed only when the speed approaches the speed of light. As a matter of fact, when it is from 0.1 up to 0.9 of the speed of light, you can compute just how it ought to vary. Now, by some happy chance the physicist has found negative electrons, namely those shot off by radium, which are going with these speeds, and hence it is possible to test our theory for these particles and see whether the rate of change of their inertia with the speed checks with the theoretical value. It is found that there is such a check. This means that there isn't any inertia in those particles which does not obey the electromagnetic laws. Therefore, we have good reason for assuming that the negative electron is nothing but a disembodied electrical charge, and that its inertia is wholly of electrical origin.

Now, with respect to the positive electron, we have not that evidence as yet, but it is obviously in the interest of simplicity to assume one kind of inertia rather than two. Further, we have a little bit of evidence upon this point, and I wish to mention what it is, because that will furnish an introduction to my sixth important modern discovery. We have good reason to think, at any rate, that there is only one positive electron in the hydrogen atom, but that the mass, or inertia of that positive is almost the mass of the hydrogen atom—at any rate we never find it any less. Now if this inertia is all electrical, then we know from theory that the charge must be more condensed in the case of the positive than in that of the negative. Consequently, if we are going to make the observed inertia of the positive hydrogen nucleus all electrical, that nucleus must be an even more dense charge, that is it must be a smaller body than is the negative electron. It was in this way that we first got the picture of an atom which has an extraordinarily minute single positive nucleus, with negative electrons around the outside. But although we first got this picture by that kind of a theory, we do not need to depend upon that theory now, because we know that the conclusion is correct. We know that the atom does consist of a body with a positive nucleus which is extraordinarily minute, and we can tell just

how large it is, provided we define the nucleus as the part of the atom that is impenetrable to the alpha rays of radium.

This brings me to the sixth of our discoveries—namely, the discovery of the nucleus atom. Let me give you just a brief statement of how we know that the atom is somewhat like a miniature solar system, with an extraordinarily minute nucleus, the size of the nucleus never being more than one one-hundred thousandth part of the diameter of the atom, with a certain number of subsidiary bodies—negative electrons—which we should liken to the planets, somewhere around the outside. How do we know that that is the case? We have this direct evidence. Nature takes a helium atom which is going with a speed of 18,000 miles per second, and nature shoots that atom right through a glass wall without leaving any hole behind, and without in any way interfering with the structure of the molecules of the glass. I can show you photographs that make the thing so clear that the wayfaring man can see it; you don't need to be a physicist. I will do so at the end of the hour, if there is time. This obviously means that the positive nucleus itself must be extraordinarily minute. Indeed the fact that the negative electron actually shoots through those hundreds of thousands of atoms without ever going near enough to any constituent of those atoms to knock any one of them out, and the fact that the positive nucleus of helium, viz, the alpha particle, shoots through even more molecules without being deflected at all from its course, causes one to wonder whether there is anything at all that is impenetrable in the atom. Why then do we say that there is a nucleus there at all? Because direct experiment says there is. There is a certain portion of the atom which the alpha particle itself can not penetrate. If the impact is head on, the alpha particle goes right up to the atom and then it backs straight back again, or if it comes up to the atom at an angle like this it goes off that way. (Illustrating.) It is only rarely that that happens, but Rutherford and Geiger and Marsden counted the percentage of alpha particles which go straight on, and the percentage which go off here, and in that manner, by perfectly simple algebraic analysis that any one of you can understand, without any assumption at all except the law of inverse squares, which can hardly be called an assumption, since we can prove that it holds, at the distance involved, for the attraction between the positive nucleus and the negative electron, we find how big that nucleus is. By the size of the nucleus—I mean the size of that portion of the atom which is impenetrable to the alpha particles. It comes out something like 10^{-13} centimeters. The diameter of the atom is 10^{-8} centimeters. Furthermore, by counting how the deflections of the alpha particles are distributed around this sphere, which we can do directly with the aid of zinc sulphide spread over

the inside of the sphere, we can obtain the number of alpha particles deflected through any given angle, and then with a little analysis of unquestionable correctness, we can find how many unit charges, positive electrons, there are in this exceedingly small nucleus, and this number comes out approximately one-half of the atomic weight.

Now, I come to another extraordinary discovery which did not merely tell us approximately how many electrons there are in the nucleus, but it told us *exactly* how many there are, and the result checked too with the number obtained by the foregoing approximate method. This brings me to the recent discoveries in the field of X rays, and I will call the seventh of the modern advances the discovery of the nature of X rays, which was virtually made by Barkla in 1904; for Barkla and others had proved that there are two types of X rays, first X rays which consist of simple ether pulses pushed off from an electron when it changes its speed; and second so-called characteristic X rays which are formed thus: When the electrons bump into a target they set something in the target into vibration, and this something sends off perfectly definite characteristic X rays, which are like monochromatic light. So, we have two types of X rays, pulse X rays, like white light, and monochromatic X rays like monochromatic light, such as comes from a mercury-vapor lamp. That is the seventh of our great modern discoveries and it must be credited chiefly to Barkla.

The eighth I will call the discovery of crystal structure by the study of X rays, which is due to Laue in Munich, and Bragg, in England. The method is simply this. You know that we analyze light by a grating which consists of a series of equally spaced lines on a reflecting or transmitting surface. With such a device we can split light up into a spectrum, but we can not thus split it up unless the width of the grating space is comparable with the wave length of the light. In the case of X rays, we had no knowledge of gratings whose grating spaces were anything like as small as the wave length of X rays, in fact such gratings were unknown until Laue had the bright idea of using the regular arrangement of the atoms in a crystal for a grating to see whether that would not do the work, and it did the work marvelously well. It was found that we could compute the grating space of certain crystals from the density and the atomic weight and then from the observed spectrum find the wave length of the X rays used. And now knowing this wave length we can work backward and find the grating-space for other crystals. We are now using this method for finding the positions and the arrangements of the atoms in crystalline bodies. Professor Bragg in his recent book on X rays and crystal structure has described this work very beautifully. Thus a whole new field of experimentation has been opened up and is being pursued in a great many laboratories,

and with particular success by A. W. Hull at the laboratory of the General Electric Co. There are almost unlimited possibilities for the chemist in the discovery by this method of the exact positions of the atoms in any kind of a crystal.

But the results of this discovery, as of most of the others which I have mentioned, are rather insignificant when compared with those of the ninth which I am going to mention, namely the discovery of the relations between the elements, and the extension of our knowledge of the radiations emitted by different substances. This discovery was made by a young Englishman only 26 years old, Moseley, who has already, unfortunately, fallen a victim to this juggernaut which is at the present time crushing out some of the finest scientific brains in the world. Moseley was killed at the age of 27, a year after he made his epoch-making discovery, and all the lives and all the interests of the eternally infamous men who made this war are not to be compared in value to the world with a hair of Moseley's head. Yet he had to be sacrificed to save a threatened civilization. A double honor to Moseley.

His discovery was this: He was analyzing the characteristic X rays which are given off when any kind of a substance is bombarded with cathode rays. The experiment was in my judgment as brilliantly conceived, as carefully and skillfully carried out, and as illuminating in its results as any which has been done in the last 50 years. What he found was this, that the atoms of all the different substances emit radiations or groups of radiations which are extraordinarily similar, but that these radiations differ in their wave lengths as we go from substance to substance.

The whole discovery can be stated in this fashion: If you take the highest frequency emitted by a given atom, and if you lay down on a table a length which is equal to the square root of this frequency, and if on top of that you lay down the square root of the frequency of the atom which has the next lower frequency, and so if you continue to lay down, with one group of ends together, the measured square root frequencies of all the elements that you can study, then what have you got? You find that you have a flight of stairs, with perfectly definite equal treads; that is, the frequencies change by definite steps as you go from element to element. And there are only four vacant treads between the lightest element which Moseley could study, namely aluminum, and the heaviest one, namely, lead, thus indicating that there are only four elements in this range which we have not already found.

An extremely interesting question is, what is the greatest common divisor of this series of steps, that is, what is the top step? There are two ways to get at it. One is by filling all the spaces up to

aluminum with known elements in the order of their weights—we can not investigate the lighter ones by the X-ray method because their frequencies are too low; at least we have not yet found how to investigate them. Now, there are just 12 lighter elements than aluminum, so we may put them all in, starting with hydrogen. That would make hydrogen correspond to the top step. The second way is to find arithmetically the greatest common divisor of the square root frequencies. This gives us a frequency which is within a few per cent of the highest frequency which hydrogen can produce, according to Lyman's measurements of optical radiations in the ultraviolet region. This indicates again that hydrogen is the element corresponding to the first step. All of this seems to mean three things, it means first that the X rays of hydrogen are just its ordinary visible radiations; second it means that Moseley opened up a whole new field of radiation, beginning with the radiations of hydrogen, and extending up to a frequency $(92)^2$ or 8464 times as high as that given by hydrogen. I have squared 92 because 92 is the number of the step corresponding to uranium, the heaviest known element, and the one having the highest frequency in its characteristic X rays.

Moseley's discovery means in the third place, almost certainly, that the elements are built up one from another by successively adding the nucleus of the hydrogen atom. The probable reason for the change in frequency as the nucleus takes on a stronger and stronger charge is that the electron sending off say the highest characteristic frequency is in a stronger electrical field in the helium atom, for example, than in the hydrogen atom, and so, as the charge on the nucleus goes up by successive steps in going from element to element, the characteristic frequencies go up by corresponding steps.

We may then picture with considerable confidence this whole physical world as built up out of one positive and one negative electron. The positive electron is the nucleus of the hydrogen atom. It is very minute in comparison with the negative, but much more massive. When two free positive electrons are tied together we have the nucleus of the helium atom. We don't know why these positives cling together. We can assume, as an hypothesis, that there are four positives in helium which are held together by two negatives, thus leaving but two free positives as experiment indicates is the case. The assumption here is that in the nucleus one negative is capable of holding two positives. This assumption would make the nucleus of any atom contain a number of negatives equal to the atomic number and a number of positives equal to twice the atomic number. So much for a very brief and incomplete sketch of Moseley's contribution to modern physics.

My last of the great discoveries of modern physics is one that I will just touch upon. It is the discovery of quantum relations in

photo-electricity, in X rays, and in optical spectra. But here I am coming to a field which we do not know very much about, which we do not yet understand, and my main motive in introducing it is to convince you that the physicist, in spite of all he knows, or thinks he knows, is a fairly modest fellow, because there are some things he knows he doesn't know, and one at present is the nature of radiation. However, we know some things about it that are new. For example, it is an extraordinarily interesting fact that when light of the X-ray type, or, indeed, light of any frequency, falls upon, say, a lithium or sodium surface, or upon almost any surface, it has the property in some way of taking hold of a negative electron in one of the atoms of that surface and of hurling that electron out with a perfectly definite speed, a speed which we can measure and which we find to be exactly proportional to the frequency of the light. That is an extraordinary phenomenon, and it is one that we explain on a kind of quantum theory, which I will not attempt to enter into here because of the fact that we have not yet worked it out fully, so that I can not give you anything very definite about it; but at any rate the quantum constant comes out of the photo-electric effect, as shown in my own work, out of X-ray work as shown by Duane and by D. L. Webster at Harvard, and out of spectroscopy work, as shown by Bohr in the beautiful theory of the atom which he has developed within the last three or four years.

I think I have brought you in this brief survey to the very outmost boundaries of our present knowledge. Bring me back 10 years from now, and we will know more about these quantum theories, but for the present I will stop, and close this hasty survey of the problems and successes of modern physics with a few reflections which are based upon historical studies.

At the University of Chicago I have a friend by the name of Dr. Breasted, who is an Egyptologist. Now Dr. Breasted tells me that he and his fellow Egyptologists have proof that less than 100 years elapsed from the time when, about 5,000 years ago, the Egyptians knew so little about building that the best they could do was to pile crude rows of uncut stone around their dead, to the time when some of the great pyramids were built, structures which represent in some ways the height of the builder's art, structures on which the surfacing is so perfect that huge granite blocks 18 feet on a side are joined together without cement, and with not as much as one one-hundredth of an inch of space anywhere between them. That kind of engineering we do not do now, luckily we do not have to do it, but it is doubtful if we could do it if we would. I am mentioning this to bring out the fact that Egypt, at that time, got the key to a certain kind of development, and pushed that development to a marvelous

degree of perfection. Indeed there was in that century, so Professor Breasted says, an industrial progress which has never been equaled at any time in the world's history until within the last 100 years, when the modern industrial revolution set in.

Go now to Greek history, and we find the same sort of a situation. About 500 B. C. the Greeks got the key to a certain type of progress, and they developed a civilization which on the intellectual side, and on the artistic and esthetic side, has never been equaled. The Greeks, like the Egyptians, got the key to a certain kind of civilization and they worked it out to marvelous perfection. But in neither case did these men or these races go on; they did not open up new fields; they did not tap new mines. Their civilization came to an apex, and then decayed; and the question has often arisen in your minds, as it has in mine, Is this age in which we are living going to follow in the same way? Have we risen to a maximum? Have we had a period of marvelous development which is going to be followed by one of decay and stagnation, or are we going to ascend to higher and higher levels? No man can answer that question; but this I know and this you know, that it was wholly unnecessary that Greek civilization, or that Egyptian civilization, should have stopped when it did. If the Egyptians and the Greeks had developed the modern scientific spirit, the spirit of search for new phenomena and new methods, they could have found them. There were plenty of new mines for them to tap, plenty of unexplored fields to search out. But they did not do it. As for us I feel just as sure as Shakespeare did that "there are still more things in heaven and earth than are dreamed of in our philosophy," and if we stop, it will be because we have forgotten the lesson which Galileo first tried to teach, and which we have been learning in the last 100 years, and that is the lesson of research. It is the lesson, the philosophy, the method, and the faith of modern physics. That is our hope, and if we keep that, if we do not call in our scouts because the rewards are larger in the applications, then I have no doubt that our civilization will go on; but if we do call in our scouts here in this country, then our civilization will give place to that of some other country which does not do so, but which learns the value for the human race of the spirit of modern scientific research.

THE EXPERIMENTS OF DR. P. W. BRIDGMAN ON THE PROPERTIES OF MATTER WHEN UNDER HIGH PRESSURE.

Introductory note by C. G. ARBOT.

[With 1 plate.]

We live in a world in which the ordinary temperature lies between the freezing and the boiling points of water, and the ordinary pressure is that of the atmosphere, or 15 pounds to the square inch. We accustom ourselves to the properties of matter under these circumstances and forget that under others the same substances might behave differently. For instance, we think of water as existing under three forms, steam, liquid, and ice, according as the temperature is a little above normal or a little below what we are accustomed to. We think of mercury as always a liquid which, on account of its very slight volatility, its heavy weight, and its being a fluid metal, though conducting electricity like other metals, is especially valuable in the laboratory, to contain gases, to enclose in thermometers and in barometers, and to use for electrical purposes. But if the temperatures prevailing in the laboratory were those of liquid air the mercury would be found to be solid like other metals and perhaps could even be used to make nails of to fasten the laboratory floors. The extraordinary electrical properties of metals at very low temperatures, as found by Dr. Kamerlingh Onnes in his experiments with the gas helium, have been mentioned in this report in an article entitled "The Discovery of Helium and What Came of It."

The properties of substances of many kinds at enormous pressures have been investigated of late years by Doctor Bridgman, and the following extracts from his published works will give the reader some impression of the difficulties of such research and the extraordinary results achieved.

The value of such researches is increased by the thought that in the formation of the earth materials which compose its crust, including minerals of many kinds, have been subjected to enormous pressures, owing to their burial miles below the surface. Without such laboratory experiments as those which Doctor Bridgman has made

it would be impossible to draw conclusions as to the effects which such tremendous compression would have, influencing the character of the geologic strata with which we are familiar. This point of view is fully recognized by geophysicists, and similar experiments at very high pressures are being carried on at the geophysical laboratory of the Carnegie Institution at Washington, where the effects of high pressures and high temperatures on terrestrial materials are principal objects of study.

HIGH PRESSURES AND FIVE KINDS OF ICE.¹

The experiments which I am about to describe are experiments in the field of very high pressures, which is a practically new field. Under conditions of high pressure many of the ordinary properties of matter are changed; and the bursting strength of vessels in which such pressures are produced is found to bear no relation to their strength under ordinary conditions. In conducting the following investigations on the effect of very high pressures on water it was found necessary to make many preliminary experiments on the strength of the containing vessels before accurate measurements of pressure could be made. In the course of this preliminary work many interesting facts concerning the behavior of materials under high pressure were disclosed. In this paper will be given, firstly, some of the results of the preliminary experiments on the strength of the containers, and then a description of the experiments made to ascertain the effect of high pressures on water. The paper will be, in large part, a record of my own experimental work.

By way of introduction it is perhaps desirable to give some idea of the magnitude of the pressures involved. The highest pressures which are ordinarily familiar to us are probably those of modern high-power artillery; the average firing pressure exerted in many of our large guns is about 2,000 atmospheres, or 30,000 pounds per square inch. The highest pressures reached in the experiments which I am about to describe are 10 times this amount; that is, 20,000 atmospheres, or 300,000 pounds per square inch. The pressure exerted at the bottom of the ocean at, say, a depth of 6 miles is about 1,000 atmospheres; a pressure of 20,000 atmospheres would, therefore, be exerted at the bottom of an ocean 120 miles deep. If the average density of the rocks of the earth's crust is taken as 2.5, 20,000 atmospheres is the pressure which prevails at a depth of 50 miles below the surface of the earth.

It should be borne in mind that in all the experiments made the pressures were produced in a liquid, which must be held in a container. It is a comparatively simple matter to produce pressures

¹ By P. W. Bridgman, Ph. D., Jefferson Physical Laboratory, Harvard University. Abstracted from *Journal of the Franklin Institute*, March, 1914.

as high as 300,000 pounds per square inch in a solid piece of steel, but it is another matter to maintain such a pressure in a liquid and prevent all leaking of the latter from the container.

The most essential part of the preliminary work was to design a packing that would keep the vessel in which the pressures were to be produced absolutely tight, and prevent the liquid from leaking from it. The feature of the form of packing finally designed is that it is made tighter and tighter by the pressure in the vessel itself; the greater the pressure in the vessel, the less can the liquid leak.

The second part of the preliminary work consisted in finding what limits of pressure steel apparatus will support, steel being selected as the best material of which to make the pressure implements. In all the experiments the pressures were produced by pushing a piston, by means of an hydraulic press, into a cylinder containing the liquid. In the piston the strain is one of compression, while in the cylinder it is one of bursting, or tension.

It was found by experiment that the best material for the piston was glass-hard steel. The compression that a piece of glass-hard steel will support when it is held rigidly so that it will not bend is surprisingly large. Several grades of steel were found that would support a compression of 600,000 pounds per square inch, and one grade supported as high as 750,000 pounds per square inch.

The strength of the steel cylinders was also a factor which had to be settled by experiment, since it was found that no theory of the strength of a cylinder is of any value for very high pressure. All ordinary theories predict that no cylinder can be stressed to more than the tensile strength of the steel, no matter how thick are its walls. A few rough experiments showed the actual pressure that a cylinder can support to be much in excess of that predicted by the ordinary theory; this is on account of the fact that when the pressure reaches a certain value the inner layers do not break but stretch, and thus allow the outer layers to assume some of their share of the load. It was found that the most efficient way to make a cylinder support a high pressure was first to stretch it on the inside by applying a much higher pressure than it was intended to maintain in practice, and then to machine it to its final diameter. A cylinder treated in this way is in a state of internal strain, exactly as is a gun which has hoops shrunk on it from the outside, the tension in the hoops inducing initial compression in the interior of the gun. When pressure is produced in such a gun, it removes the compression from the inner layers of the material and the tension of the outer layers is increased. But it has been shown that the tension in the inner layers increases more rapidly than that in the outer, and it can be seen, therefore, that, in time, the increasing

tension in the inner layers neutralizes the compression which existed there initially and eventually equals the increasing tension of the outer layers, with the result that finally the stress throughout the mass of the cylinder is one of uniform tension. In an ideal condition all parts of the cylinder would be ready to break at the same time, and then the maximum possible strength would result; in any actual case it is, of course, impossible to reach this ideal, but, with the cylinders subjected to a preliminary stretching, it can be approached much more nearly than even in a built-up gun.

The best steel to use for the cylinder is found to be a steel which will stretch considerably before breaking, but which has, at the same time, a high tensile strength. The best of all was a steel made in this country by the electric furnace method; this steel is a chrome vanadium steel, and has, when hardened in oil, a tensile strength that may reach as high as 300,000 pounds per square inch. The highest pressure that I have ever found it possible to reach in a cylinder has been 40,000 atmospheres, or twice the highest pressures at which I have made accurate measurements.

In the preliminary work on steel cylinders many cylinders were broken. This gave opportunity for interesting observations on the manner of rupture at high pressures, and two facts not to be expected according to ordinary theories were noted. The first was the enormous amount of stretch that the steel at the inner layer of a cylinder will support without rupture; this is well shown in plate 1, figures 1, 2, and 3. In the first figure the cylinder was originally one-half inch in diameter, but it stretched to one and one-fifth inches before breaking. The second observation was that in all the cylinders tested the break started at the outside, where the stress and the strain are both least; this was observed in all the steels used. There is reason to believe, however, that very brittle substances like glass would break at the inside, as predicted by the ordinary theory. The fact seems to be that if the substance is brittle it will break at the inside first, but that if it is at all plastic it will break at the outside first, the crack traveling into the inside.

In addition to the data obtained regarding the manner in which materials break at high pressures, many other peculiar facts were noted during these preliminary tests. Perhaps the most interesting of these is the increase in rigidity experienced in substances ordinarily soft and pliable. A striking example of this is afforded in the case of paraffin, which under pressures as high as 20,000 atmospheres becomes more rigid than soft steel, so that if paraffin is forced to flow by the application of a very high pressure, and a piece of soft steel is imbedded in it, the steel will flow with the paraffin and will become distorted and twisted with the latter. Soft rubber also becomes very hard and brittle under high pressure; in



FIG. 1.—ONE OF THE HALVES OF A CYLINDER OF TOOL STEEL SPLIT BY THE APPLICATION OF INTERNAL PRESSURE.

The inner hole has stretched from $\frac{1}{8}$ inch to $1\frac{1}{2}$ inches. The maximum pressure withstood by this cylinder was 30,000 atmospheres.

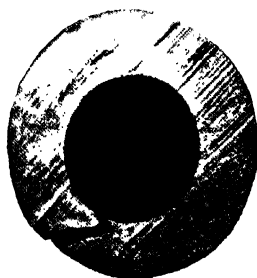


FIG. 2.—CROSS SECTION OF A CYLINDER OF BESSEMER STEEL RUPTURED BY THE APPLICATION OF INTERNAL PRESSURE.

This cylinder was originally 2 inches outside and $\frac{1}{8}$ inch inside diameter. The inner hole has been stretched to $1\frac{1}{2}$ inches.



FIG. 3.—VIEW OF THE OUTSIDE OF THE CYLINDER SHOWN IN FIG. 2, TAKEN BEFORE THE SECTION WAS MADE.

one experiment a soft rubber washer became so brittle that it cracked like glass, and a soft steel washer in contact with the rubber was forced by the pressure in ridges into the cracks in the rubber, thus showing that the rubber had become harder than the steel.

Another all-important task in the preliminary experiments, in addition to that of finding what pressures the steel vessels could stand, was to devise some way of accurately measuring the pressure. The very simplest method that can be conceived proved to be the best in this case. It consists in inserting a steel piston through a hole in the wall of the cylinder and measuring the force necessary to prevent it from being blown out by the pressure within. There are many mechanical difficulties in realizing such a method as this, the most obvious being to overcome leakage. To do this the piston must fit the hole tightly, but at the same time must fit so freely that there is not enough friction to destroy the accuracy of the readings obtained by its means. It was found possible, by using a small-diameter piston fitting into a comparatively long hole, to take care of both these factors. With the gauge as finally constructed, pressures up to 13,000 kilograms per square centimeter were measured with an accuracy of one-tenth per cent. After high pressures had been successfully measured with such a gauge, it was found possible to construct gauges of a much more convenient form for actual use, and to calibrate them against this, which became an "absolute" gauge. One gauge that I have used in most of my later work is a manganin resistance gauge, which consists of a coil of manganin wire placed in the pressure cylinder and connected through insulated leads with apparatus for measuring the resistance. The electrical resistance of this coil is found to change directly proportionally with changes of pressure in the cylinder. Manganin is a very much more convenient material to use than any pure metal, since the resistance of all pure metals decreases as the pressure increases, and the decrease is moreover, not proportional to the increase of pressure.

After the completion of the preliminary work, in which the methods of producing and accurately measuring high pressures had been decided upon, it was decided to obtain, first of all, measurements of compressibilities. The first substance chosen for the measurement of compressibility was water, chiefly as it is so common a substance, and because many measurements had been made on it previously at low pressures. Water is not absolutely incompressible, as is commonly supposed, but its volume may be very appreciably diminished by the application of sufficiently high pressures. Under 12,000 atmospheres a decrease of volume of about 20 per cent is produced. The measurements of the compressibility of water by the new method were found to be satisfactory at comparatively low pressures, but at

higher pressures there were, quite frequently, discrepancies which could not be explained by errors in the apparatus. The temperature of these measurements was that of the room, about 20° C.

Apparently the only possible explanation of the irregularities shown was that the water had been frozen by the high pressure, so that measurements of the volume at high pressures were sometimes being made on the liquid and sometimes on the solid. This explanation, if it were the true one, indicated a very remarkable state of affairs, as the application of ordinary pressures to ice causes it to melt. One would expect to be able to melt ice by high pressure, therefore, and not to freeze water.

However, the discoveries of Tammann materially assist in providing an explanation of the irregularities found in the compressibility measurements referred to above.

Tammann had discovered that at high pressures there are two modifications of ice, each of which is denser than water. It would be expected that the freezing point of the modified form would be raised by the application of pressure, so that possibly the irregularities could be explained by the freezing of water to this new form of ice at 20° C. under the very high pressures reached in this work, which were about five times those reached by Tammann. But the fault in this explanation is that Tammann had predicted from measurements on this new kind of ice that no pressure, however great, could possibly raise the freezing point of water higher than about -17° , and a temperature of $+20^{\circ}$ C. was being employed. Careful investigation of the whole matter was therefore called for, and special apparatus had to be designed to attack the new problem.

To state that it is possible in the experiments to ascertain whether the water has frozen to ice or not may appear strange, when it is considered that the ice is inclosed in a cylinder and can never be seen, because as soon as the pressure is removed and the cylinder opened the ice immediately liquefies. As a matter of fact, this can not be ascertained, except indirectly. When the water freezes to ice, there is a decrease in volume, and this is shown by a drop in pressure. Conversely, too, when ice melts to water the volume increases, which is indicated by an increase of pressure.

In the actual measurements the temperature of the water was kept constant. In order to increase the pressure, the piston was pushed into the cylinder, the distance being measured, and the displacement of the piston plotted against the increase of pressure produced. The pressure at first increased regularly as the displacement, but when the pressure reached a value high enough to freeze the water at the particular temperature of the experiment the volume suddenly decreased without the pressure rising at all. Then, after freezing was completed, so that there was only solid ice in the apparatus, the pres-

sure resumed its regular rise with the displacement. This is illustrated by the curve in figure 4, in which the abscissae represent pressures and the ordinates displacements.

The pressure at which the piston falls into the cylinder without producing a rise of pressure (that is, the vertical part of the curve in fig. 1) is the pressure at which the water freezes to ice at the particular temperature of the experiment. For every temperature the pressure at which the water freezes is different. When the ice is denser than water the freezing temperature increases as the pressure increases. In this way it is possible to find at what pressure water

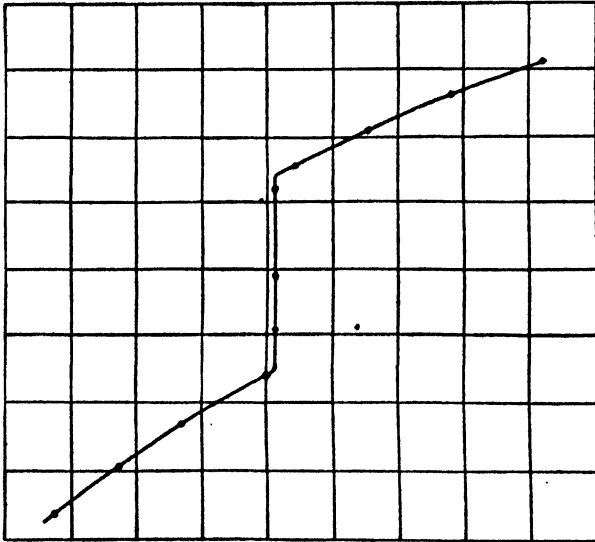


FIG. 1.

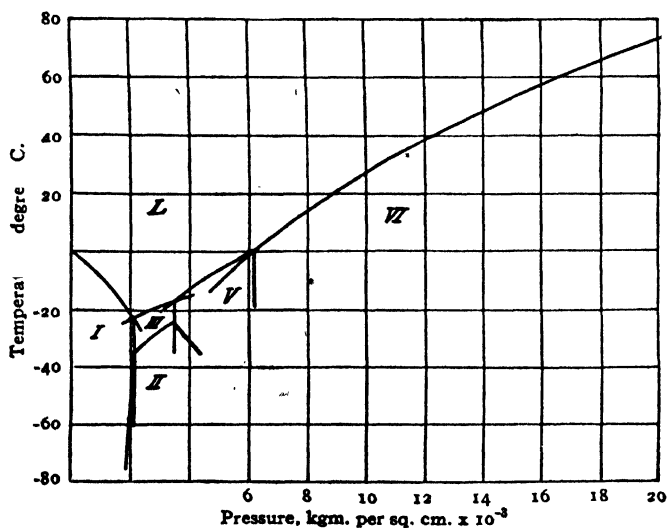
freezes for any given temperature, and so to construct so-called "melting curves."

It will be noted that the method given above, besides determining the pressure at which water freezes at a given temperature, determines another factor. The amount by which the piston is pushed in while the pressure remains constant evidently indicates the change of volume in the water while freezing, from which the difference in volume between the water and the ice can be computed. If we know the density of the water, we can calculate immediately the density of the ice. This is important data, since if both the temperature and pressure at which the ice melts are known, together with the change of volume, the amount of heat necessary to melt the ice can also be computed.

The method of experiment outlined above is not original with the writer, and has, in fact, been employed by many other previous ex-

perimenters. The only important difference is that the new packing which I devised makes it possible to obtain a piston which has absolutely no leak, even at the highest pressures, and so renders possible accurate measurements of the change of volume. This has, I believe, not been possible before. In all previous experiments there has been some leakage around the piston, which made it impossible to obtain accurate measurements of the change of volume.

To return now to the compressibility measurements and the discrepancies found at high pressure, the application of the present method of experiment to the study of water showed that there did exist a new variety of ice at the high pressures, as had been suspected. It was found that the new variety of ice was not one of those



The equilibrium diagram between the liquid and the five solid modifications of water.

FIG. 2.

two kinds previously discovered by Tammann, but was, instead, considerably denser than either of the varieties found by him. In addition to this new kind, which is stable at high temperatures and pressures, I discovered still another kind, not previously known, intermediate between the new high-pressure ice and the two varieties found by Tammann, making four varieties of ice denser than water. There are, therefore, in all at least five different kinds of ice, only one of which we are ordinarily familiar with.

Figure 2 shows more clearly the relation between these different kinds of ice. It will be noted that in this figure there are five regions, numbered according to the kind of ice to be found within the region. Thus, for example, if in an experiment the pressure be raised to 10,000 or 10⁴ kgm. and the temperature maintained at 0°,

these corresponding to the point 10 on the diagram, the water substance will be found to exist in the form of ice VI. Or, again, if the pressure is 2,000 or 2×10^3 kgm. and the temperature $+20^\circ$ (point on the diagram 2, 20), then the water substance is in the form of ordinary liquid water; or, thirdly, if the pressure is 1,000 or 10^3 kgm., and the temperature -20° (point on the diagram I, -20), then the water substance is in the form of ice I, the form we are ordinarily familiar with.

On any of the boundary lines of the regions in figure 2 the two adjacent forms of water substance are in equilibrium with each other, but if the state of the mass be changed slightly so that it is represented by a point within either of the regions, the kind of ice in that region prevails and the other disappears. Thus, let us suppose that there is ordinary ice, ice I, at say -10° and atmospheric pressure, in the apparatus at the beginning of an experiment, then if the pressure be increased (keeping the temperature constant at -10°) at about 1,000 or 10^3 kgm. (point I, -10), the ice melts to water. But if now we continue to increase the pressure, at about 4,400 or 4.4×10^3 kgm. (point 44, -10), the liquid water freezes again to a new kind of ice, ice V, which is denser than water. If we still further increase the pressure, at about 6,300 or 6.3×10^3 kgm. (point 6.3, -10), the ice V suddenly changes to ice VI, the volume again decreasing during the change. Or, if we commence at atmospheric pressure and -30° (point 0, -30), and increase the pressure, we first change ice I (ordinary ice) into ice III, then, on still further increasing the pressure, ice III changes to ice II; on further increase, II changes to V, and finally V changes to VI. The high temperature to which the curve between ice VI and the liquid runs is of interest; by the application of 20,000 or 20×10^3 kgm. we may freeze water, although it is nearly boiling hot.

The manner in which one ice changes into another is truly remarkable. We know that water freezes slowly or that ice melts slowly, but some of these kinds of ice will change into another kind so rapidly that the reaction reminds one of an explosion. For instance, if ice I is changed to ice III at -25° , the reaction takes place so suddenly that it is impossible to follow the change of pressure which takes place after the reaction. On several occasions I have heard a click in the apparatus when the transformation took place, so rapid was it. Still another remarkable thing is that the effect of temperature on the velocity of the reaction is very great indeed. If ice I is cooled to about -50° , the reaction occurs so slowly that it takes hours for its completion. Similar behavior is found also on the curves III-V and V-VI; the reaction from one solid form to another is very rapid indeed at temperatures near the melting temperature, but as the temperature is reduced the speed of the reaction becomes very much less.

This is the reason that the curves separating the domains of the different kinds of ice could not be followed to lower temperatures than are shown in the diagram. At lower temperatures the reaction becomes so very slow that it would have taken days to obtain a single point. It is to be expected that the curves separating II and V and V from VI will continue to run to lower temperatures, that they will finally meet, and that from the point of intersection a new equilibrium curve, the curve between II and VI, will start. The point at which any three curves meet in the diagram is called a triple point. It will be noticed from the figure that two curves never meet without a third curve starting from the point of intersection of the other two. This is always true, provided that on two of the curves there is a phase in common; it may be proved mathematically that such is the case, but to prove this here would take us too far afield.

The fact that ice I gives place to ice II at a certain pressure has one practical application. We have often heard of the immense pressures developed when water is allowed to freeze in a closed vessel. Burst water pipes are a familiar example of this, and there are also well-known experiments in which cannon balls have been split open by freezing water. It is of interest to inquire how much pressure might be reached in this way. The diagram furnishes an answer to the question, as it shows that if the pressure on the ice during freezing should rise too much over 2,000 or 2×10^3 kgm., corresponding to 30,000 pounds per square inch, the ordinary ice would change to ice III, which has a much less volume, so that the ice would tend to shrink and the rise of pressure would be arrested. Thirty thousand pounds per square inch is, therefore, the highest pressure that can be obtained by freezing water in a closed space.

A word as to the possibility of proving that the various new forms of ice that have been described are really solids. All that has been shown in the experiments is that at certain pressures and temperatures there is a sudden change of volume. This must mean a change of some kind in the molecular structure of the substance, but on what grounds can it be said that the change is a change to solid form? May not there conceivably be two modifications of the liquid? The answer is, first, that no substance is known which has two modifications of the liquid, but that many are known which have two solid forms. None of our ideas of the molecular structure of solids or of liquids would lead us to think that two liquid forms of a substance are possible. Secondly, Tammann has given direct experimental proof that the two forms of ice, II and III, are really solid. He did this by cooling the cylinder containing the ice to the temperature of liquid air, and then opening the cylinder after pressure had been relieved, still keeping the temperature at that of liquid air. Of course, as soon as pressure was relieved, the ice II or III, whichever it happened to be, became unstable, but at this low temperature the reac-

tion from the unstable to the stable, or ordinary ice, runs very slowly indeed, so that there was time enough to examine the contents of the cylinder, after opening it, before all the unstable variety had disappeared. It was found that the new substance was indeed a solid, and that as it changed into ordinary ice it increased greatly in volume. Tammann performed this experiment for both the varieties II and III. It might perhaps be possible to repeat the experiment for the other two varieties, V and VI, but the chances of success are very much less, because atmospheric pressure is so much further removed from the equilibrium pressure for these two varieties that the reaction would be expected to run very much more rapidly. What is more, the behavior of these new varieties is in all respects like that of the two varieties which we know to be solid; that is, under some conditions the reaction velocity is much greater than it ever is when a liquid passes to a solid. Also, in some cases when one variety changes to another, enough pressure is exerted on the thin steel vessel containing the ice to rupture it. It is difficult to conceive how a liquid would develop enough pressure to rupture a steel vessel; one would expect instead that it would flow away, relieving the pressure as fast as it was formed. The overwhelming probability from all the evidence is, therefore, that the other two varieties, V and VI, are solid also.

THE COAGULATION OF ALBUMEN BY PRESSURE.¹

If the white of an egg is subjected to hydrostatic pressure at room temperature it becomes coagulated, presenting an appearance much like that of a hard-boiled egg. In my experiments the albumen was inclosed in a nickel-steel case and pressure transmitted to it by mercury. Pressure may be applied so slowly that the rise of temperature due to the compression is inappreciable. At room temperature (20°) the limits of pressure necessary to produce the coagulation were fairly well marked. A pressure of 5,000 atmospheres (75,000 pounds per square inch) applied for 30 minutes produced a perceptible stiffening of the white, but little more; 6,000 atmosphere for 30 minutes produced a coagulation in appearance like curdled milk; while 7,000 for 30 minutes resulted in apparently complete coagulation, the white being capable of standing under its own weight.

I have made no attempt to determine whether the nature of the coagulation produced by pressure is the same as that produced by heat. If one can judge by appearances the two may be different. In the course of 24 hours there separates from the pressure-coagulated white a small quantity of some watery fluid, in which the coagulated part remains insoluble.

TWO NEW MODIFICATIONS OF PHOSPHORUS.²

The two modifications of phosphorus to be described here were obtained during an investigation of the effect of high pressure on the

¹ Abstracted from the *Journal of Biological Chemistry*, Vol. XIX, No. 4, 1914.

² Extracted from the *Journal of the American Chemical Society*, Vol. XXXVI, No. 7, July, 1914.

melting point of ordinary white phosphorus. The two new forms have perfectly distinct characteristics; in this they are different from the questionable modifications of red phosphorus often announced. The first of these modifications is a new form of white phosphorus, which changes into the ordinary white modification reversibly under the proper conditions. The second is a form obtained irreversibly from white at high pressures and moderate temperatures, which is 15 per cent more dense than Hittorff's "metallic" red phosphorus.

WHITE PHOSPHORUS II.

The new modification of white phosphorus was first produced by increasing pressure on ordinary white phosphorus to about 11,000 kg./cm.² at 60°. The existence of the new form was shown by a discontinuous change in the volume at this pressure. A number of points on the transition curve of these two modifications were then obtained at temperatures down to 0°, and the corresponding changes of volume, when one modification passes to the other, were measured.

The appearance of this new form in bulk is much like that of ordinary white phosphorus. It may possibly be a trifle yellower, and there are likely to be cracks formed because of the volume contraction of about 2 per cent when the transition occurs.

An attempt to obtain the crystalline form was partially successful. A solution of white phosphorus in carbon disulphide was allowed to crystallize at the temperature of a mixture of carbon dioxide snow and gasoline. The phosphorus separates out as a slush composed of fine crystals. Microscopic examination showed that the usual crystalline habit is in needles, about five times as long as broad, with pointed ends of about 60°. It was not possible to specify further the shape of the needles. Scattered among the needles, however, there were occasional plate-like forms of unmistakable hexagonal shape; several nearly perfect hexagons were found. The great probability is, therefore, that this new modification belongs to the hexagonal system. The crystalline form of the usual modification is regular.

BLACK PHOSPHORUS.

Black phosphorus was discovered during an attempt to force ordinary white phosphorus to change into red phosphorus by the application of high hydrostatic pressure, at a temperature below that at which the transformation runs with appreciable velocity at atmospheric pressure. Pressure up to about 6,000 kilograms per square centimeter was applied at room temperature to the phosphorus through the medium of the kerosene; the cylinder was raised to 200° in an oil bath controlled by a thermostat, and the pressure was then

raised to from 12,000 to 13,000 kilograms. The transition from white to black phosphorus occurs under these conditions in from 5 to 30 minutes. The pressure drops at first very slowly, then more rapidly, until apparently a critical point is reached somewhere between 11,000 and 12,000, at which it drops suddenly to about 4,000 kilograms. Pressure may then be increased again (with the form of apparatus used this secondary increase could not be carried beyond 11,000 kilograms) with no further drop of pressure. On cooling the lower cylinder and relieving pressure, the white phosphorus is found transformed into a black substance of very much smaller volume than the original white phosphorus. Proof will be given presently that this is a modification of phosphorus, not a compound. This experiment has been repeated successfully every time that it has been tried, now five times in all. About 50 grams of black phosphorus may be formed at a time.

An attempt to form black phosphorus from white at 175° and nearly 13,000 kilograms was without success. Also an attempt to produce black phosphorus from commercial powdered red phosphorus, which had been inoculated with a small piece of black phosphorus, was without result in 40 minutes at 12,900 kilograms and 200° . Another attempt to produce black phosphorus from the massive red phosphorus, to be described later, was also unsuccessful after 30 minutes at 12,900 kilograms and 200° .

The black phosphorus presents two distinct characteristic fractures. In some places the fracture is coarsely granular like sugar, apparently crystalline, but the grains under a low-power microscope show no semblance of crystalline form. In other places where the flow under pressure was great, the fracture is fibrous with a metallic luster, very much like graphite in appearance. In spite of the high pressure of formation, the mass of the black phosphorus is permeated with pores, some of which may be several millimeters in diameter. These pores may at first be filled with kerosene. The presence of these pores doubtless accounts for the slight apparent increase in weight of the specimen after the transformation.

In order to prove that the substance formed was really a new modification of phosphorus and not a compound, a colleague very kindly made an analysis of two samples at the chemical laboratory of Harvard University. The results of the analysis are as follows:

Weight of black phosphorus.	Weight of $\text{Mg}_2\text{P}_2\text{O}_7$.	Per cent. phosphorus.
0.1622 .1754	0.5669 .6182	87.5 98.3

The most striking difference between the new black phosphorus and previously known modifications is its high density. The density of ordinary solid white phosphorus is 1.83, and that of red phosphorus may vary according to the method of preparation from 2.05 to a maximum of 2.34 for Hittorff's "metallic" crystallized red phosphorus. Nine determinations of the density of different specimens of black phosphorus were made. We accept the value 2.691 as the true density of black phosphorus, a value 15 per cent higher than that of the most dense variety of red phosphorus. The conclusion is inescapable that this is a new modification of phosphorus, quite distinct from red phosphorus, and because of its higher density presumably a more stable form.

Black phosphorus does not catch fire spontaneously, can be ignited with difficulty with a match, and may be heated to perhaps 400° in the air without spontaneous ignition. Unlike commercial red phosphorus, it can not be ignited by striking with a hammer on an anvil. It is almost, if not entirely, stable in the air. A few simple tests seemed to show that it is much like red phosphorus in chemical properties; it is attacked by cold nitric acid, is not acted on appreciably by sulphuric acid, and is not dissolved by carbon disulphide.

When black phosphorus is heated in a closed glass tube it vaporizes and condenses in the colder parts of the tube to red and white phosphorus. The appearance under these conditions is exactly the same as when red phosphorus is similarly treated. It would seem, therefore, that the vapors of black and red phosphorus are, at least in large part, identical.

Black phosphorus is a fairly good conductor of electricity, in distinction from white and red phosphorus, which in the pure state seem to be nearly perfect insulators. The specimen of black phosphorus whose conductivity was measured here was selected from all the available pieces for its great apparent compactness. It was prepared by turning in a lathe, leaving for the final test a cylindrical piece about 1.52 centimeters in diameter and 2.69 centimeters long. The electrodes were attached by copper plating terminals on the plane ends and soldering copper wires to the copper plating.

The value found for the specific resistance is 0.711 ohms per centimeter cube at 0°. The temperature coefficient of resistance has a large negative value, and between 0° and 75° the relation between temperature and resistance is nearly linear. At 0° it is -0.00465 . This is an unusually high value, higher than for any substance usually listed. It is about 10 times higher than for carbon, and makes it practically certain that the small amount of carbon known to be present can not be taking a large share in the conduction. It should be remarked that in respect to the sign of the temperature coefficient black phosphorus is not like the metals.

It may pay to pause here to take thought of this conductivity of black phosphorus. Here is a substance which in two modifications possesses no electrical conductivity, but in some way, when the atoms are rearranged more closely together, sets free electrons and becomes a conductor. As we might expect from its electrical conductivity, black phosphorus is also a rather good conductor of heat.

THE RELATION OF THE SEVERAL MODIFICATIONS.

The most important problem connected with this new modification is the determination of its relation to the other known modifications of phosphorus. It was hoped that the existence of this new modification might offer some clue to the vexed question as to the true nature of red phosphorus. Some facts of importance have been found, but the exact nature of the relationship has not yet been discovered.

In the light of experiments [here omitted] the explanation is suggested that red phosphorus is a transformation product from white phosphorus to something else, in which the transformation has not run to completion, but is prevented by friction.

With regard to the relation between black and red phosphorus we can offer only conjectures. It does seem pretty certain, however, that red and black can not stand in the relation of ordinary monotropic solids. If they did bear this relation, the black must be the more stable form, because of its lower vapor pressure, and in this case we can not understand the failure of the red to condense as black out of its vapor. The fact that the black apparently melts to the same liquid as the red is puzzling. It may be that the relations here are the same as in the vapor phase; that is, liquid black phosphorus may be unstable, and may transform itself irreversibly to liquid red as rapidly as it is formed.

In a later paper¹ Doctor Bridgman gives by the aid of diagrams the evidences of transformations of 30 substances. Some are solid, others liquid in their ordinary forms, but like water and phosphorus they each change into several solid modifications of new properties when placed under different conditions of temperature and immense pressure. In addition to these he has examined about a hundred other substances which do not show such transformations. No doubt all these facts will be made use of in the now rapidly progressing new theory of the internal structure of atoms and molecules which has been born out of the discovery of radio-activity.

Doctor Bridgman's views in regard to the nature of the phenomenon are expressed as follows:

A crystal is supposed to be composed of units, atoms, or molecules, as the case may be, which remain the same in different polymorphic forms. Poly-

morphism is to be regarded in its most general aspect as due to regrouping of these units in different arrangements. One of the units is to be thought of as terminated by rigid boundaries; that is, each unit has shape as definite as a brick has shape. Furthermore at different localities on the surface of the units there are localized centers of force (attractive usually), so that two units, if free, will tend to come together with a definite orientation. A crystal is to be regarded as a system in which a compromise has been affected between the arrangement which the units would take in virtue of the action of the localized centers of force, the arrangement into which the units would be urged by external pressure or the mean internal pressure so as to occupy the smallest possible volume, and the chaotic disarray which temperature agitation tends to produce.

One implication of the view that regards crystals as built from blocks of definite shape is especially insisted on. Only in exceptional cases will the edifice constructed from the blocks be such that there will be no unfilled crevices around the corners, and in no case where there are two possible structures of different volumes will such empty spaces be absent in at least one of the structures. These empty spaces are to be thought of as playing an essential part in the phenomena of polymorphism.

THE ELECTRICAL RESISTANCE OF METALS UNDER PRESSURE.¹

In this paper the effect of pressure combined with temperature on the electrical resistances of 22 metals is investigated. The pressure range is from atmospheric pressure to 12,000 kilograms per centimeter square and the temperature range from 0° to 100°. The apparatus is in all essentials the same as that previously used. It consists of two parts, an upper and lower cylinder connected by a stout tube. In the upper cylinder pressure is produced by the descent of a piston driven by a ram. The upper cylinder is kept at constant temperature and contains the coil of manganin wire which gives the pressure by its change of resistance. The lower cylinders of two different lengths were used, according as the wire to be measured was insulated and so could be coiled into a narrow space or was bare and had to be wound in spiral grooves on a core.

It is essential that the method of winding be such that the pressure is transmitted freely to all parts of the coil without any mechanical hindrance from the frame on which it is wound. This object is obviously at once obtained when the wire is wound on itself without a core, but this method is feasible only when the wire can be covered with silk insulation without damage. If the wire is soft like lead it can not be covered without damage and must be wound bare on some sort of a core. Several attempts were made before suitable material for a core was found. At first hard rubber was used, but this is so compressible that at the highest pressures the wire drops out of the grooves and is so expansible that at the highest temperatures the wire is stretched.

¹ Abstracted from Proceedings American Academy of Arts and Sciences, Vol. 52, No. 9, Feb., 1917.

Finally, bone was found to be satisfactory from both points of view.

Precautions relating to the freedom of constraint from the viscosity of the transmitting medium, the purity of the substances examined, the accuracy of the temperature determinations, and the seasoning of coils by exposures to high pressures and various temperatures were carefully attended to. Measurements of the change of resistance were made at intervals of 1,000 kilograms at 0°, 25°, 50°, 75°, and 100°. Two readings were made at the maximum and two zero readings, one before and one after the run. There is usually no perceptible "hysteresis" or difference between the readings on increasing pressure and those found later on decreasing pressure. I had not expected results so favorable.

After every change of pressure some time is necessary before the next reading can be made because of temperature disturbance due to the heat of compression. This change of temperature is in many cases so great as to entirely mask the effect of change of pressure. The effect is very troublesome, as it may need as much as 30 or 45 minutes to reach temperature equilibrium for each change of pressure. Without some trick of procedure, a run at a single temperature might occupy seven or eight hours and is excessively tedious. This was avoided by running somewhat beyond the pressure desired and then, after most of the heat of compression had been dissipated, bringing the pressure back to the desired mark. With a little practice temperature equilibrium is reached in five or seven minutes. If the apparatus is in good running order a complete run on one substance at one temperature could usually be made in about two hours, and, including all manipulations, runs at two different temperatures could easily be made on a single substance in a working day.

GENERAL CHARACTER OF RESULTS.

The effect of pressure on all the metals tried, with the exception of antimony and bismuth, is to decrease the resistance. To a first approximation the relation between pressure and resistance is linear. To a second approximation the relation is not linear, but the initial rate of decrease of resistance is in all cases greater than that at higher pressures.

In the case of some of the softer metals, unusual means were taken both in the preparation of the wire and in its use, which may be of interest to the reader. As, for example, consider indium. A sample of only 1 gram in amount was available. This metal is as soft or softer than lead. It was extruded—that is, forced out—into a wire of 0.006 inch diameter with a die of special construction. Indium oxidizes much less rapidly than lead; after extrusion the

surface of the wire is brightly polished and remains so for several weeks when exposed to the air. It was wound loosely on a bone core. Connections were made by soft soldering with a miniature copper, using a fusible solder of melting point slightly above 100°. There is some difficulty in making a successful soldered connection because of the low melting point of indium, which is about 155°. It alloys very rapidly with any ordinary solder, forming an alloy of much lower melting point than any of the constituents. It must be caught by the solder with a single well directed touch.

Successful runs were made at 0°, 25°, and 50°, but at 75° the soldered connections dropped off. Difficulty because of alloying also made it necessary to omit the usual temperature seasoning. This in any event is not so necessary for a low melting metal as for a higher one.

Without going into the details of Doctor Bridgman's measurements, in which he follows the changes of the various phenomena observed as they depend upon pressures and temperatures at different magnitudes, it may be interesting to the reader to give a brief summary of the behavior of a score of metals with regard to the coefficient of change of resistance for varying temperature and varying pressure. I take this data from Doctor Bridgman's publication without intending to imply that it is altogether new.

Resistance coefficients.

Metal.	For temperature at 0 kgr. 0-100° C. per degree.	For pressure at 25° C. 0-12,000 kgr. per 1,000 kgr.
Indium.....	0.00407	-0.01051
Tin.....	.00447	- .00928
Thallium.....	.00517	- .01165
Cadmium.....	.00424	- .00910
Lead.....	.00441	- .01222
Zinc.....	.00416	- .00463
Magnesium.....	.00390	- .0055
Aluminum.....	.00434	- .00379
Silver.....	.00407	- .00334
Gold.....	.00400	- .00288
Copper.....	.00429	- .00181
Nickel.....	.00487	- .00150
Cobalt.....	.00365	- .00080
Iron.....	.00621	- .00228
Palladium.....	.00318	- .00189
Platinum.....	.00387	- .00186
Molybdenum.....	.00434	- .00128
Tantalum.....	.00297	- .00144
Tungsten.....	.00322	- .00124
Antimony.....	.00473	+ .01220
Tellurium.....	- .0063	- .12
Bismuth.....	.00441	+ .0198

In regard to the details of the results, for which the reader should consult the original paper, Doctor Bridgman says:

To sum up: Different metals show minor irregularities in behavior, but they are alike in several general features which must be the first task of any theory to explain. These general features are the approximate constancy of pressure coefficient with temperature, and the accompanying constancy of temperature coefficient with pressure; contrasted with this the pronounced decrease of instantaneous pressure coefficient with rising pressure. It has been obvious enough that the data have presented no spectacular features, and I must confess to a sense of disappointment that an extension of the pressure range to at least fourfold that of previous measurements has brought out no striking new facts to reward the extra effort. When the magnitude of the change of volume produced by a pressure of 12,000 kilograms is considered, however, it does seem that the results acquire a physical significance great enough to justify the extension of the range. The volume of many of the metals at 0° C. and 12,000 kilograms is less than the volume at atmosphere pressure and 0° Abs. The resistance of most metals tends toward zero at 0° Abs., but under great pressure at 0° C., at the same volume as at the absolute zero, the resistance is only a few per cent less than under normal conditions. Any valid theory must explain the surprisingly little effect of the element of volume alone apart from the element of temperature. It is furthermore known that at very low temperatures the connection between resistance and temperature changes its character; the relation ceases to be linear, and the resistance curve approaches the origin tangentially to the temperature axis. Whether the abrupt discontinuity shown by several metals a few degrees above 0° Abs. is an effect of a polymorphic transition does not yet seem to be settled. It is significant that no trace of any such effect is to be found at room temperature as the volume is decreased toward and beyond its value at 0° Abs. The question whether there is a change in the character of the resistance curves as the volume approaches that at 0° Abs. could not, of course, have been answered by measurements over a small pressure range; it is perhaps some justification of the extension of range that this question can now be answered.

An estimation as to the comparative volumes at (12,000 kg., 0° C.) and (0 kg., 0° Abs.) is given in the accompanying table. The values of compressibility used in the computations have been taken from Richards, assuming constancy over the pressure range, and the volume at 0° Abs. has been taken from the data of Ch. Lindemann on linear expansion to 20° Abs.

Comparison of changes of volume produced by temperature and pressure.

Metal.	Change of volume between 0° C. and 0° Abs. at 0 kg.	Change of volume between 0 kg. and 12,000 kg. at 0° C.
Lead.....	0.0189	0.0275
Zinc.....	.0057	.0200
Aluminum.....	.0036	.0173
Silver.....	.0108	.0119
Copper.....	.0078	.0089

In general, the data are given for the change of resistance of 22 metals between 0° and 100° C. over a pressure range from 0 to 12,000 kilograms. Three of the metals are abnormal; bismuth and antimony both have a positive pressure

coefficient, and the pressure coefficient of tellurium has an abnormally large negative value. The other 19 metals are of different behavior, but in broad outline the behavior of all is alike.

In his last published investigation¹ Doctor Bridgman has examined the thermo-electric properties of 22 metals, including thermo-electromotive force, Peltier heat, and Thomson heat:

The results of this paper, unlike those of the previous paper on resistance, are almost entirely novel; the nature of the results to be expected was not known, and accordingly these effects, so far as affected by pressure, were not available for any theoretical considerations. Previous measurements on the effect of pressure on thermo-electromotive force are very few in number, and cover a very restricted range. The maximum pressure heretofore reached has been by Wagner, 300 kilograms.

The range employed in this work covers 20 pure metals and 2 alloys and all pressures up to 12,000 kg./cm.² and all temperatures between 0° and 100°. The nature of the results was unexpectedly complicated. The normal state of affairs is apparently a positive effect of pressure on both Peltier and Thomson heats, but there are numerous examples of negative effects, and almost none of the metals show regular variation of these quantities with pressure and temperature within the range. Three metals, tin, iron, and aluminum, show complicated variations of the thermo-electromotive force. The unexpected complications found make these results disappointingly meager in their suggestions as to the nature of the thermoelectric mechanism. The results suggest most strongly that the thermoelectric mechanism must be complicated, that it can not be at all of the simplicity imagined by the free electron theory, and that most likely the effects which we measure are the resultant of different effects, which sometimes, at least, work in opposite directions. What these effects may be, we are not in a position at present to speculate.

It may not be too daring to say that it seems to me that much of my previous work on high-pressure effects at least suggests a direction in which we may look for the explanation of these complications. I have shown in detail that probably the properties of both liquids and solids are to be explained in terms of the same agency, the effect of the characteristic shape of the atoms, or, if one prefers to express it so, the nature of the field of force surrounding the atom. It seems most probable that the electrons in passing from atom to atom, or in playing about between the atoms, may be subjected to forces changing in a complicated way as the atoms are forced into positions of varying degrees of adaptation to each other's irregularities.

¹ Proceedings of the American Academy of Arts and Sciences, Vol. 53, 1918.

THE PROBLEM OF RADIOACTIVE LEAD.¹

By THEODORE W. RICHARDS, *Harvard University.*

We meet to-day with happiness which six months ago would have seemed beyond the bounds of reasonable hope. After anxious months, the confidently awaited victory, which last spring still seemed far away, has crowned the cause of justice, truth, and liberty. We in America rejoice that this cause is our cause, and that at the most critical time we were able to render effective help to the staunch and brave allied forces which had fought so long and so nobly.

The object of this address is not, however, to appraise the military issues of the great war so fortunately ending, nor to deal with the weighty international problems now faced by the world, but rather to bring before you other considerations, having to do with the advancement of science.

The particular subject chosen, namely, the problem of radioactive lead, is one of peculiar and extraordinary interest, because it involves a readjustment and enlargement of many rather firmly fixed ideas concerning the chemical elements and their mutual relations, as well as the nature of atoms.

Within the last twenty years the definition of these two words, "elements" and "atoms," has been rendered somewhat uncertain and bids fair to suffer even further change. Both of them are ancient words, and both even a century since had acquired meanings different from those of long ago. Thales thought of but one element, and Aristotle's elements—earth, air, fire, water, and the quintessence, derived perhaps from yet more ancient philosophy—were not plentiful enough to account for all the manifold phenomena of nature. Democritus's old idea of the atom was associated rather with the philosophical conception of indivisibility than with the idea of chemical combination in definite proportions. To-day many chemists and physicists think that the chemical atoms of the last century are no longer to be considered as indivisible. In that case, the old Greek name "atom" is no longer fitting, because it denotes indivisibility. Some one has even facetiously suggested that the word "tom"—indicating divisibility—would be more appropriate. Moreover, if

¹ Address of the president of the American Association for the Advancement of Science, Baltimore, December, 1918. Reprinted by permission from *Science*, N. S., Vol. XLIX, No. 1253, pp. 1-11, Jan. 3, 1919.

our so-called atoms are really divisible, we can not but be somewhat doubtful as to our definition of the ultimate elements of the universe. The reason for this new turn of thought is due, as you all know, to the discovery of the unexpected and startling phenomena of radioactivity.

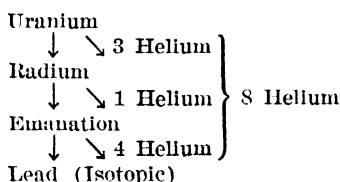
To-night we have to deal with a substance directly concerned with the iconoclastic radioactive changes—with the very phenomena which cause us to stop and think about our definitions of atoms and elements. For the lead obtained from radioactive minerals appears to have resulted, together with helium, from the radioactive decomposition of elements of higher atomic weight. Skeptical at first, the whole chemical world has now come to acknowledge that the well-defined element, helium (discovered by Sir William Ramsay 23 years ago), is one of the decomposition products of radium. Radium itself is a substance which, in many respects, acts as an element, with 226 as its atomic weight, and must be considered as the heaviest member of the well-known calcium family; but its atoms appear to be so big and so complex as to disintegrate because of lack of stability. The disintegration is slow, and not to be hastened or retarded by any agency known to man; 1,670 years are demanded for the decomposition of half of any given portion of radium, according to the exact measurements of Professors Boltwood and Gleditsch. Moreover, we have reason to believe that this decomposition proceeds in a series of stages, successive atoms of helium (five in all) being evolved with different degrees of ease by any given atom of radium. In the end most, indeed probably all, of the residual part of the radium appears to have been converted into the peculiar kind of metallic lead with which we are concerned to-night. The nature of the end-product was first suggested by Boltwood, who pointed out the invariable presence of lead in radium minerals. Thus we must accept a kind of limited transmutation of the elements, although not of the immediately profitable type sought by the ancient alchemists.

Interesting and significant as all of this is, nevertheless the whole story has not yet been told. Radium itself appears to come from the exceedingly slow decomposition of uranium, an inference drawn from the fact that radium is found only in conjunction with the uranium, which even after careful purification soon becomes radioactive and gives every indication of suffering slow disintegration. Moreover, uranium is not the only other heavy element which appears to be capable of decomposing and yielding elements of lower atomic weight. Another, thorium, has a like propensity, although the steps in this case are perhaps not so fully interpreted, nor so generally accepted. In the process of disintegration all these heavy atoms yield strange radiations, some of them akin to, or identical with X rays, which bear away that part of the colossal energy of disintegration

not made manifest as heat. These facts have been proved beyond doubt by the brilliant work of Professors Becquerel, Marie Curie, P. Curie, Sir Ernest Rutherford, and others.

The nature of the rays, and of the highly interesting evanescent transition products and their relation to one another, is too complex for discussion now. We are concerned rather with the nature of the more permanent of the substances concerned—especially with the starting point, uranium (possessing the heaviest of all atoms), radium, and the lead which seems to result from their disintegration. Omitting the less stable transition products, the most essential outcomes are roughly indicated by a sort of genealogical tree herewith shown:

HYPOTHESIS CONCERNING THE DISINTEGRATION OF URANIUM.



Thus each atom of uranium is supposed to be converted into radium by losing three atoms of helium, and each atom of radium is supposed to be converted into a kind of lead by losing five more, as already stated.

If uranium can thus disintegrate, should we call it an element, and should we call its smallest particles atoms? The answers depend upon our definition of these two words. If the word "element" is supposed to designate a substance incapable of disintegration, apparently it should not be applied to uranium; neither should the word "atom" be applied to the smallest conceivable particles of this substance. But no one would now maintain that any element is really incapable of disintegration. A method of still retaining the terms in this and analogous cases is to define an element as "a substance which has not yet been decomposed artificially," that is to say, by the hand of man—and an atom as "the smallest particle of such a substance, inferred from physicochemical behavior." The atom, then, is not to be considered as wholly indivisible, but only as indivisible (or at least as not yet divided) by artificial means. For, as in the case of radium, the disintegration of uranium can not be hastened or retarded by any known earthly agency.* So long as it stays intact, the atom of uranium behaves quantitatively in the same fashion as any other atom: Dalton's laws of definite and multiple combining proportions apply without exception to its compounds. In this connection one should remember that the atomic theory, as a whole, including Dalton's and Avogadro's generalizations, is not

in the least invalidated by the new discoveries of radioactivity. On the contrary, the atomic theory is entrenched to-day more firmly than ever before in its history.

Interesting speculations by Doctors Russell, Fleck, Soddy, and Fajans and others have interpreted in extremely ingenious and plausible fashion the several transitory steps of the changes, and indicate the reasons why the end products of the decomposition both of uranium and thorium should be very similar to lead, if not identical with it. Therefore a careful study of the properties of lead of indubitably radioactive origin became a matter of great interest, as a step toward confirming these speculations, especially in comparison with the properties of ordinary lead. Such investigations should throw light on the nature of radium and uranium and the extraordinary changes which those metals suffer. Moreover, by analogy, the resulting conclusions might be more or less applicable to the relations of other elements to each other; and the comparison of this new kind of lead with ordinary lead might afford important information as to the essential attributes of elementary substances in general, in case any differences between the two kinds should be found.

Before the subject had been taken up at Harvard University, chemists had already recognized the fact that the so-called uranium-lead is indeed qualitatively very like ordinary lead. It yields a black sulphide, a yellow chromate, and a white sulphate, all very sparingly soluble in water, just as ordinary lead does. Continued fractional crystallization or precipitation had been shown by Professor Soddy and others to separate no foreign substance. Hence great similarity was proved; but this does not signify identity. Identity is to be established only by quantitative researches. Plato recognized long ago, in an often-quoted epigram, that when weights and measures are left out little remains of any art. Modern science echoes this dictum in its insistence on quantitative data; science becomes more scientific as it becomes more exactly quantitative.

One of the most striking and significant of the quantitative properties of an element is its atomic weight—a number computed from the proportion by weight in which it combines with some other element, taken as a standard. There is no need, before this distinguished audience, of emphasizing the importance of the familiar table of atomic weights; but a few parenthetical words about their character is perhaps not out of place. As has been more than once said, the atomic weights of the relatively permanent elements, which constitute almost all of the crust of the earth, seem to be concerned with the ultimate nature of things, and must have been fixed at the very beginning of the universe, if indeed the universe ever had any beginning. They are silent, apparently unchanging witnesses of the transition from the imagined chaos of old philosophy to the existing cosmos. The crystal

of quartz in a newly hewn piece of granite seems, and probably is, as compact and perfect as it was just after it was formed, eons ago. We can not imagine that any of its properties have essentially changed during its protracted imprisonment; and, so far as we can guess, the silicon and oxygen of which it was made may have existed for previous eons, first as gas, and then as liquid. The relative weights in which these two elements combine must date at least from the inconceivably distant time when the earth "was without form and void."

Although, apparently, these numbers were thus determined at the birth of our universe, they are, philosophically speaking, in a different class from the purely mathematical constants such as the relation of circumference to the diameter of a circle. 3.14159 ... is a geometrical magnitude entirely independent of any kind of material, and it therefore belongs in the more general class of numbers, together with simple numerical relations, logarithmic and trigonometric quantities, other mathematical functions. On the other hand, the atomic weights of the primeval elements, although less general than these, are much more general and fundamental than the constants of astronomy, such as the so-called constant of gravity, the length of the day and year, the proper motion of the sun, and all the other incommensurable magnitudes which have been more or less accidentally ordained in the cosmic system. The physicochemical constants, such as the atomic weights, lie in a group between the mathematical constants and the astronomical "constants," and their values have a significance only less important than the former.

In the lead from uranium we have a comparatively youthful elementary substance, which seems to have been formed since the rocks in which it occurs had crystallized. Is the atomic weight of this youthful lead identical with that of the far more ancient common lead, which seems to be more nearly contemporary as to its origin with the silicon and oxygen of quartz?

The idea that different specimens of a given element might have different atomic weights is by no means new—it far antedates the discovery of radioactivity.

Ever since the discovery of the definite combining proportions of the elements and the ascription of these proportions to the relative weights of the atoms, the complete constancy of the atomic weights has occasionally been questioned. More than once in the past investigators have found apparent differences in the weights of atoms of a single kind, but until very recently all these irregularities have been proved to be due to inaccurate experimentation. Nevertheless, even 30 years ago the question seemed to me not definitively answered, and careful experiments were made with copper, silver and sodium, obtained from widely different sources, in the hope of find-

ing differences in the atomic weights; according to the source of the material. No such differences whatever were found. More recently Professor Baxter has compared the atomic weights of iron and nickel in meteorites (from an unknown, perhaps inconceivably distant source) and the same terrestrial metals. In these cases also the results were negative. Thus copper, silver, sodium, iron and nickel all appeared to be perfectly definite in nature, and their atoms, each after its own kind, all alike.

The general question remained, nevertheless, one of profound interest to the theoretical chemist, because it involved the very nature of the elements themselves; and in its relation to the possible discovery of a difference between uranium lead and ordinary lead, it became a very crucial question.

Early in 1913, when the hypothesis of radioactive disintegration had assumed definite shape, Doctor Fajan's assistant, Max Lambert, journeyed to Cambridge, bringing a large quantity of lead from Bohemian radioactive sources in order that its atomic weight might be determined by Harvard methods. The Carnegie Institution of Washington gave generous pecuniary assistance toward providing the necessary apparatus in this and subsequent investigations.

The most important precautions to be taken in such work are worthy of brief notice, because the value of the results inevitably depends upon them. The operation consists in weighing specimens of a salt of the element in question and then precipitating one of the constituents in each specimen, determining the weight of the precipitate, and thus the composition of the salt. In the first place, each portion of substance to be weighed must be free from the suspicion of containing unheeded impurities, otherwise its weight will mean little. This is an end not easily attained, for liquids often attack their containing vessels and absorb gases, crystals include and occlude solvents, precipitates carry down polluting impurities, dried substances cling to water, and solids, even at high temperatures, often fail to discharge their imprisoned contaminations. Especial care was taken that each specimen was as pure as it could be made, for impurity in one would vitiate the whole comparison.

In the next place, after an analysis has once begun, every trace of each substance to be weighed must be collected and find its way in due course to the scale pan. The trouble here lies in the difficulty in estimating, or even detecting, minute traces of substances remaining in solution, or minute losses by evaporation at high temperatures.

In brief, "the whole truth and nothing but the truth," is the aim. The chemical side of the question is far more intricate and uncertain than the physical operation of weighing. The real difficulties

precede the introduction of the substance into the balance case. Every substance must be assumed to be impure, every reaction must be assumed to be incomplete, every measurement must be assumed to contain error until proof to the contrary can be obtained. Only by means of the utmost care, applied with ever-watchful judgment, may the unexpected snares which always lurk in complicated processes be detected and rendered powerless for evil.

After all these digressions, made in order that the problems concerned should be clearly recognized, let us turn to the main object of our quest. In the present case each form of lead was first weighed as pure chloride, and the chlorine in this salt after solution was precipitated as silver chloride, the weight of which was determined. Precautions too numerous to mention were observed. Thus, the weight of chlorine in the salt was found, and by difference the weight of the lead. From the ratio of weights, the atomic weight of lead was easily calculated. Since the question involved especially a comparison of the two kinds of lead, particular care was taken that each sample should be treated in precisely the same way. Even if a constant error had existed in the method, it could not have affected the comparison, since each result would have been influenced in identical degree.

The outcome of our earliest trials, published in July, 1914, brought convincing evidence that the atomic weight of the specimen of uranium lead from Bohemia is really less than that of ordinary lead, the value found being 206.6 instead of 207.2—a difference of 0.3 per cent, far beyond the probable error of experiment. Almost simultaneously preliminary figures were made public by Doctors Hönigschmid and St. Horovitz and Maurice Curie, pointing toward the same verdict.

This result, interesting and convincing as it was, was only a beginning. Other experimenters abroad have since confirmed it, especially Dr. Otto Hönigschmid; and many new determinations have been made at the Wolcott Gibbs Memorial Laboratory, with the assistance of Dr. Charles Wadsworth, 3d, and Dr. Norris F. Hall, upon various samples of lead from radioactive sources in widely separated parts of the world. Messrs. E. R. Bubb and S. Radcliff, of the Radium Hill Co., of New South Wales, kindly sent a large quantity of lead from their radium mines, and a particularly valuable specimen prepared from selected crystals of pure mineral was put at our disposal by Dr. Ellen Gleditsch—not to mention other important contributions from others, including Professor Boltwood and Sir William Ramsay. Each of these samples gave a different atomic weight for the lead obtained from them, and the conclusion was highly probable that they contained varying admixtures of ordinary lead in the uranium-radium lead. This was verified by the knowledge

that in at least some cases the uranium ore actually had been contaminated with lead ore. The purest Norwegian specimen contributed by Miss Gleditsch thus acquired especial importance and significance, because it was only very slightly, if at all, vitiated in this way. As a matter of fact, it gave 206.08 for the atomic weight in question—the lowest of all. Here are typical results, showing the outcome; many more of similar tenor were obtained.

Atomic Weights.

Common lead.....	$\left. \begin{array}{l} 207.20 \\ 207.19 \end{array} \right\}$	207.19
Australian radioactive lead containing probably 25 per cent ordinary lead.....	$\left. \begin{array}{l} 206.32 \\ 206.36 \\ 206.33 \\ 206.36 \end{array} \right\}$	206.34
Purest uranio-lead.....	$\left. \begin{array}{l} 206.08 \\ 206.09 \end{array} \right\}$	206.08

Hönigschmid, from similar pure material, had found figures (206.05) agreeing almost exactly with the last value. One can not help believing that this last specimen of lead is a definite substance, probably in a state almost pure, because of the unmixed quality of the carefully selected mineral from which it was obtained.

A further question now arises: is it a *permanent* substance—really an end-product of the disintegration? Soddy's hypothesis assumes that it is. The only important fact militating against this view is the observation that uranium-lead is always radioactive, and hence might be suspected of being unstable. In various impure specimens, however, the radioactivity is not proportional to the change in the atomic weight; hence the radioactivity is probably, at least in part, to be referred not to the lead itself, but rather to contamination with minute, unweighable amounts of intensely radioactive impurities—other more transitory products of disintegration.¹ If weighable, such impurities would almost certainly *increase*, not *diminish*, the atomic weight; hence their presence could not account for the low value.

Let us compare the actual result for the atomic weight of this kind of lead with the theory of Soddy and Fajans. If this theory is sound, the simple subtraction of eight times the atomic weight of helium from that of uranium, or five times the atomic weight of helium from that of radium, should give the atomic weight of the lead resulting from the disintegration, as follows:

¹ For this reason the term "radio-active lead" although it describes the fact, is perhaps, from a theoretical point of view, not the best designation of either uranium or thorium lead; but the term is convenient, because it distinguishes between these two forms and common lead.

Hypothetical calculation of atomic weight of uranium-lead.

Atomic weight of uranium.....	=	238.18	
8 × atomic weight of helium.....	=	32.00	
Residue (lead?)	206.18	=	206.18
Atomic weight of radium.....	=	225.96	
5 × atomic weight of helium.....	=	20.00	
Residue (lead?)	205.96	=	205.96
Average hypothetical value for lead.....		=	206.07
Observed value for uranium-lead ¹		=	206.08
Difference			0.01

The agreement is remarkably good. Each of the individual calculated values shows less than 0.05 per cent. deviation from the average, and the average itself shows essential identity with fact—a striking confirmation of the theory. This is perhaps the most successful attempt on record to compute an atomic weight from hypothetical assumptions. Usually we are wholly at a loss as to the theory underlying the precise relationships, and must determine our values by careful experiment alone.

The value 206.08 for the atomic weight of lead has further support in the fact that it is more nearly half way between thallium, 204, and bismuth, 208, the two neighboring elements in the periodic system, than is the atomic weight 207.2 possessed by ordinary lead. It appears, then, that 206, the value pertaining to uranium-lead, is a very reasonable value.

But, as has been repeatedly pointed out, ordinary lead, constituting the vast bulk of the lead in the world, has without doubt a much higher atomic weight, 207.2, not to be expected from either of the lines of reasoning just given. In order to test the uniformity of this circumstance, Professor Baxter, with the help of one of his assistants, investigated ordinary lead from the nonuraniferous ores from many parts of the world, and discovered that the constancy of its quantitative behavior is as striking as that of copper or silver. His figures agreed very closely, within the limit of error of experimentation, with those obtained as a part of the present comparison of the two kinds of lead, so that there could be no question as to lack of identity of methods or precautions.

Before leaving the subject of the relative atomic weights of these two types of lead, it is not without interest to note the exact absolute weights of the atoms. If, as we have excellent reason for believing on the basis of the brilliant work of Professor Millikan, a so-called

¹ This is the Harvard result. If Hönigschmid's value is given equal weight, the average observed value would be 206.07, exactly identical with the hypothetical value.

gram-atom (the atomic weight in grams) contains 606.2 sextillion actual atoms, the weights of the atoms of the two kinds of lead must be respectively 342 and 340 septillionths of a gram. Their extreme smallness, as regards bulk, may perhaps best be inferred from the consideration that the smallest object visible as a point in the common microscope has a diameter probably about one thousand times as great as an atom of lead.¹

Evidently, on the basis of the quantitative results just exhibited, we must admit that there is at least one real difference between radioactive lead and the common metal. Are there other differences?

A question as to the density of each substance, and, therefore, as to the bulk occupied by the respective atoms, at once arises. Since the atom of uranium-lead weighs less than the other, it must occupy less space, supposing that it has the same density; or else it must have less density, supposing that it should occupy the same space. The identity of the chemical behavior of the two types of lead suggests the probability of the latter alternative, and this was, therefore, assumed by Soddy; but experimental proof was evidently desirable. Therefore, an extended investigation of the density of the various kinds of lead was carried out likewise in the Gibbs Memorial Laboratory. As a matter of fact, the densities of the several specimens were found to be very nearly proportional to their atomic weights; that is to say, the bulk of the atom of radioactive lead is almost exactly the same as the bulk of the atom of ordinary lead, although the weights of these atoms are so markedly different.

Densities and atomic volumes.

	Atomic weight.	Density	Atomic volume.
Pure uranio-lead.....	236.08	11.273	18.281
Australian mixture.....	236.34	11.289	18.278
Pure common lead.....	207.19	11.337	18.277

A distinctive property of elementary substances, which has always been supposed to be concerned more or less definitely with the atomic weight, is the spectrum, depending upon the wavelengths of light emitted by the vapor. But, surprisingly enough, the spectrum lines produced by these two sorts of lead, when heated to the high temperature of the electric arc, are so precisely alike, both as to their wavelengths and their intensities, that no ordinary spectrum analysis shows any difference whatever. This has been proved by careful

¹ If the smallest object visible in a microscope could be enlarged to the width of this printed page, the atoms in it would appear about the size of the dots on the letters i, or the periods in the type used in this footnote.

experiments at Harvard and elsewhere. A¹ and B were from two different specimens of radioactive lead, C from ordinary lead, all very carefully purified. The range covered is about from 3,000 to 2,000 wavelength—far in the ultra-violet. Very recently Prof. W. D. Harkins, of Chicago, and two assistants, have detected, with a very extended grating spectrum, an exceedingly minute shift (0.0001 per cent of the wavelength—an amount far too small to be shown by the spectra exhibited) of one of the lines. The wonder is, not that there should be a difference, but rather that they should be so very nearly identical. Evidently the considerable difference in the atomic weight produces only a barely perceptible effect on the wavelengths of light emitted by the several isotopic forms of a given element, although a less difference in atomic weight between two different elements (for example, cobalt and nickel) is concomitant with utterly divergent spectra.

Another very interesting question, involving the relations of substance both to light and to weight (or rather density) is its refractive index. All the formulæ relating to molecular refraction involve the *density* of the substance concerned. In the case under consideration, do the differing weights of the atoms, and therefore the differing densities of the same compounds of the two kinds of lead, affect the refractive indices of the salts? Is the refractive index of a given salt of radioactive lead identical with that of the same salt of ordinary lead? Evidence on this point would go far to decide whether density or atomic volume is the more important thing in determining refractive index. A very careful study carried out with the help of Dr. W. C. Schumb at Harvard has within the past few months shown that as a matter of fact the refractive index of ordinary lead nitrate is identical with that of the nitrate of radioactive lead within one part in nearly twenty thousand, a result which shows that density is a less important factor in determining refractive index than had been previously assumed.

Both of these conclusions concerning light—that drawn from the spectra and that drawn from the refractive indices—have a yet more far-reaching interest, for they give us a further clue as regards the innermost nature of the atom. That part of the atom which determines its weight seems to have, at least in these cases, very little effect on that part of the atom which determines its behavior toward light.

Immediately connected with the question of density of the solid salts is the question as to the densities of their saturated solutions, as well as to the extent of saturation. Fajans and Lembert had recently obtained results probably indicating that the molecular solubility of each kind of lead is the same, and that the densities of the solutions are different, the density of the radioactive solution being less to an extent consistent with the smaller molecular weight. These results,

¹ References are to photographs not reproduced here.

however, left much to be desired in the way of accuracy, and needed verification. Therefore a very careful investigation, begun at Harvard with the assistance of Schumb, before the appearance of Fajan's publication, furnished valuable knowledge on this point.

Solubility of two kinds of lead nitrate.¹

	Common lead.	Uranium lead.
Per cent salt in saturated solution (25.00°).....	37.342	37.280
Grams lead per 100 grams water.....	37.281	37.130
Molecular solubility per 1,000 grams water.....	1.7993	1.7989

¹ The uranium lead used in these determinations was a specimen from Australia having the atomic weight 206.11, not quite like the earlier sample, but not different in important degree.

Here, again, differences in weight alone are manifest, and these are proportional to the differences in the atomic weights; the molecular behavior is essentially identical in the two sorts.

The identity in solubility might also be inferred from the impossibility of separating the two kinds of lead from each other by fractional crystallization. This was predicted by Soddy, and tested by him and by others. Various vain attempts have been made to separate the different kinds of lead from one another, but apparently when once they are mixed, no ordinary method can separate them, since the properties of the different kinds are so nearly alike. The latest attempt at the Gibbs Memorial Laboratory involved 1,000 fractional crystallizations of the Australian lead nitrate, which is believed to contain both ordinary and uranium-radium-lead. The extreme fraction of the crystals (representing the least soluble portion, if any difference in solubility might exist) gave within the limit of error the same atomic weight as the extreme fraction of the mother liquor (representing the most soluble portion), thus confirming the work of others in this direction.

When wires constructed of two different metals are joined, and the junction heated, an electrical potential or electromotive force is produced at the junction. This property seemed, then, to be a highly interesting one to test, in order to find out how great may be the similarity of the two kinds of lead. In fact, wires made of radioactive lead and ordinary lead tested in the Gibbs Laboratory gave no measurable thermoelectric effect, the wires acting as if they were made of the same identical substance, although the atomic weights and densities were different. No other case of this sort is known, so far as I am aware. The melting points of the two kinds of lead were likewise found, with the assistance of N. F. Hall, to be identical within the probable accuracy of the experiment.¹

¹ Since this address was first published Prof. P. W. Bridgman has found that both the electrical conductivity of the two kinds of lead, and the effect of pressure on this conductivity, are likewise identical; and Prof. W. Duane has found that even the X-ray spectra of the two kinds show no difference.

Let us bring all these results together into one table, so that we may better grasp their combined significance.

Comparison of properties of different kinds of lead.¹

	Common lead.	Mixture (Austrian).	Uranio-lead.	Percentage difference.	
	A	B	C	A-B	A-C
Atomic weight.....	207.19	206.34	206.08	0.42	0.54
Density.....	11.337	11.289	11.273	0.42	0.56
Atomic volume.....	18.277	18.278	18.281	0.01	0.02
Melting point (absolute).....	600.53	600.59	.....	0.01	.....
Solubility (metal as nitrate).....	37.281	37.130	.....	0.41	.....
Refractive index of nitrate.....	1.7815	1.7814	.....	0.01	.....
Thermoelectric effect.....	.....	.....	.....	0.00	.....
Spectrum wavelength.....	.....	.....	.....	0.00	0.00

Summed up in a few words, the situation appears to be this: At least two kinds of lead exist—one, the ordinary metal disseminated throughout the world, in nonuraniferous ores; another, a form of lead apparently produced by the decomposition of uranium, radium being one of the intermediate products. If we leave out of consideration the probably inessential difference in radioactivity, the two kinds are very closely, if not exactly, alike in every respect, excepting atomic weight, density, and immediately related properties involving weight, such as solubility. Thorium lead may be a third variety, with similar relations. Shall we call these substances different elements, or the same? The best answer is that proposed by Professor Soddy, who invented a new name, and called them “isotopes” of the same element.

Since every new fact concerning the behavior of the elements gives a new possible means of discovering something about their nature, and since these facts are of especially significant kind, the anomaly is of more than passing interest, and may be said to constitute one of the most interesting and puzzling situations now presented to the chemist who looks for the deeper meanings of things.

Many new queries arise in one's mind from a study of the data. Among them is a question as to the nature of ordinary lead, which possesses a less reasonable atomic weight than the radioactive variety. Why should this state of things exist?

Ordinary lead may be either a pure substance, or else a mixture of uranium-lead with lead of yet higher atomic weight, perhaps 208. The latter substance might be formed, as Soddy points out, if thorium (over 232) lost six atoms of helium, and he and Hönigschmid have found quantitative evidence of its existence in thorium minerals.

After reviewing all the data, Prof. F. W. Clarke has brought forward an interesting and reasonable hypothesis explaining the

¹ For the sake of better comparison, all the results given are those obtained at Harvard. No results of experiments elsewhere are inconsistent with these.

difference between the several kinds of lead. He points out that whereas we have every reason to believe that uranium and thorium lead are the results of disintegration of heavier atoms, ordinary lead may be imagined to be the product of a far earlier synthesis or evolution from smaller atoms. The hypothesis might be supported by the analogy of the synthesis and decomposition of organic substances, which by no means always follow similar paths; it seems to be consistent with most, if not all, of the facts now known.

On the other hand, may not the uniformity of ordinary lead and its difference from either of the radioactive leads be almost equally capable of interpretation in quite a different fashion? Whenever, in the inconceivably distant past, the element lead was evolved, it is hardly to be supposed that uranium-lead and thorium-lead could have been entirely absent. The conditions must have been chaotic and favorable to mixture. When the two or more forms were mixed, none of the processes of nature would separate them. Therefore they must appear millions of years afterwards in an equally mixed state on earth, constituting our ordinary lead. There may have been more than two forms of lead; but two forms, one possessing an atomic weight 206 and the other, an atomic weight over 208, would account for all the facts. The identity in nature of all the common lead on earth might indicate merely that at one time all the matter now constituting the earth was liquid or gaseous in violent agitation, so that all the kinds of lead were thoroughly commingled before solidification. This explanation, if it could be confirmed, would furnish important evidence concerning the early history of planets. So far afield may a difference of half a per cent in weight between two kinds of atoms so small as to be far beyond the possible range of our most piercing means of actual observation, carry the inquiring investigator!

The true answers to these questions are not to be found by speculation, such as that just detailed, however suggestive such speculation may be. They are to be found by careful observation. For example, the doubt as to the nature of ordinary lead can only be decided by discovering whether or not it may be separated into two constituents. Since weight (or mass) is the only known quality distinguishing between the several isotopes or kinds of lead, weight (or mass) must be made the basis of separation. Hence the chief hope of separating isotopes of lead lies in the method of fractional diffusion, as has been already suggested by many other experimenters on this subject. Promising preliminary experiments preparatory to such an undertaking have already been begun at Harvard, and before long more light may be obtained.

The idea that other elementary substances also may be mixtures of two or more isotopes has been advanced by several chemists. Espe-

cially if ordinary lead should really be found to be thus complicated, many, if not all, other elements should be tested in the same way. The outcome, while not in the least affecting our table of atomic weights as far as practical purposes are concerned, might lead to highly interesting theoretical conclusions.

How can such remote scientific knowledge, even if it satisfies our ever-insistent intellectual curiosity, be of any practical use? Who can tell? It must be admitted that the practical value is apparently slight as regards any immediate application, but one can never know how soon any new knowledge concerning the nature of things may bear unexpected fruit. Faraday had no conception of the electric locomotive or the power-plants of Niagara when he performed those crucial experiments with magnets and wires that laid the basis for the dynamo. Nearly 50 years elapsed before his experiments on electric induction in moving wires bore fruit in a practical electric lighting system; and yet more years before the trolley car, depending equally upon the principles discovered by Faraday, became an everyday occurrence. At the time of discovery, even if the wide bearing and extraordinary usefulness of his experiments could have been foreseen by him, they were certainly hidden from the world at large.

The laws of nature can not be intelligently applied until they are understood, and in order to understand them, many experiments bearing upon the ultimate nature of things must be made, in order that all may be combined in a far-reaching generalization impossible without the detailed knowledge upon which it rests. When mankind discovers the fundamental laws underlying any set of phenomena, these phenomena come in much larger measure than before under his control, and are applicable for his service. Until we understand the laws, all depends upon chance. Hence, merely from the practical point of view, concerning the material progress of humanity, the exact understanding of the laws of nature is one of the most important of all the problems presented to man; and the unknown laws underlying the nature of the elements are obviously among the most fundamental of these laws of nature.

Such gain in knowledge brings with it augmented responsibilities. Science gives human beings vastly increased power. This power has immeasurably beneficent possibilities, but it may be used for ill as well as for good. Science has recently been blamed by superficial critics, but she is not at fault if her great potentialities are sometimes perverted to serve malignant ends. Is not such atrocious perversion due rather to the fact that the ethical enlightenment of a part of the human race has not kept pace with the progress of science? May mankind be generous and high-minded enough to use the bountiful resources of nature, not for evil, but for good, in the days to come!

SPHAGNUM MOSS: WAR SUBSTITUTE FOR COTTON IN ABSORBENT SURGICAL DRESSINGS.¹

By Prof. GEORGE E. NICHOLS,
Osborn Botanical Laboratory, Yale University.

[With 4 plates.]

INTRODUCTORY.

Along in the late seventies of the last century a laborer at one of the outlying peat moors in northern Germany accidentally sustained a severe lacerated wound of the forearm. In the absence of anything better to use his fellow workmen bound up the wound with fragments of the peat which happened to be lying near, and it was not until 10 days later that the man was able to secure surgical attention. Imagine the surprise of the surgeon when, on removing the improvised dressing, it was found that the injury had completely healed.²

With this incident the use of sphagnum in present-day surgery may be said to have originated. As a matter of fact, however, its use in this connection is not a new thing at all; it is merely a modern and scientific revival of a very ancient practice. In parts of Great Britain, according to Porter,³ from time immemorial bog moss has been used by country people in the treatment of boils and discharging wounds. In Scotland and Ireland it was employed many centuries ago for practically the same purpose that it is being used to-day; and moss was "at least recommended for use by army surgeons, both in the Napoleonic and the Franco-Prussian wars."

We must acknowledge our indebtedness to the Germans, however, for demonstrating the value of the sphagnum in the modern, antiseptic methods of surgery. Following the incident which has been mentioned above, investigations were set on foot as to the nature and the properties both of the sphagnum and of the peat to which it gives rise, and a number of papers were published in German medi-

¹ Text in part taken from a paper entitled "Sphagnum Moss and Its Use in Surgical Dressings," published in the *Journal of the New York Botanical Garden*, Vol. 19, September, 1918.

² This incident is related by Neuber (*Arch. f. klin. Chir.* 27: 757-788, 1882), a German surgeon who at that time was connected with the surgical clinic at Kiel.

³ Porter, J. B. Sphagnum surgical dressings. *Internat. Jour. Surgery* 30: 129-135, f. 1-8. 1917. Reprinted as a separate by the Canadian Red Cross.

cal journals, in which the sphagnum, as related to surgical practice, was discussed from various points of view; and within a very few years this moss came to be accepted in Germany as a standard material for surgical dressings, being used not only in private practice but in some of the largest hospitals. Outside of Germany the sphagnum is known to have been used in this country by at least one prominent surgeon fully 20 years ago, but in general its value for use in surgical dressings has not been appreciated until quite recently.

USE OF SPHAGNUM SURGICAL DRESSINGS DURING THE RECENT WAR.

Sphagnum was probably first used on a large scale during the Russian-Japanese war, when it was extensively employed by the Japanese as a first-aid dressing. "Many of the wounds thus dressed with sphagnum were not inspected again until the patient reached Japan, which often took 10 days, but almost invariably the wound was in good condition; much better it is said than when cotton was used."¹

The history of its use in the recent war is somewhat as follows. Shortly after the outbreak of the war it began to be feared in England that there might be a serious shortage of cotton, and experiments were made with various materials—oakum, wood pulp, and even sawdust—in the hope of finding some satisfactory substitute. It was at this time that attention was directed by C. W. Cathcart, an Edinburgh surgeon attached to the British Army medical forces, to the neglected possibilities of the sphagnum.² In 1914 sphagnum dressings were given a thorough try-out at one of the large war hospitals in Scotland, and the results proved so satisfactory that sphagnum was at once recommended for general use. In September, 1915, sphagnum dressings were formally accepted by the British war office. At this time the total British output of sphagnum surgical dressings was barely 250 a month. But the work rapidly assumed large proportions, and we are informed by the London Graphic for September 2, 1916, that the collecting and drying of sphagnum moss and making it up into surgical dressings "has become a national industry" in Scotland, and that "the work is being extended all over England, Ireland, and Wales." By the end of 1916 the monthly output of sphagnum surgical dressings from British organizations had come to exceed 200,000.

On this side of the Atlantic the importance of the sphagnum enterprise was first brought into prominence early in 1917, by Professor J. B. Porter, of McGill University. Largely through his efforts a

¹ Hotson, J. W. Sphagnum as a surgical dressing. pp. 1-31. *f. 1-18.* Bulletin issued by the Northwest Division of the American Red Cross. Seattle, 1918. Reprinted in *Jour. Amer. Peat Soc.* 11: 195-226. 1918.

² See especially a paper by Cathcart, C. W., and Balfour, I. B., in the *Scotsman*, for November 17, 1914, and one by Cathcart in *Brit. Med. Jour.* 38: 137-139. 1915.

strong sphagnum organization was built up by the Canadian Red Cross, which, during the summer of 1918, was turning out upwards of 200,000 sphagnum dressings per month. The total British output of sphagnum surgical dressings toward the end of the war is estimated to have been in the neighborhood of 1,000,000 per month.

The sphagnum work of the American Red Cross was organized under the leadership of the late Harry James Smith, brilliant New York playwright, in the East, and of Professor J. W. Hotson, of the University of Washington, in the West. Although the sphagnum was not formally approved by the American Red Cross until March, 1918, more than half a million sphagnum surgical dressings were turned out in this country between this time and the cessation of hostilities. Most of these were made by the Chapters in the Pacific Northwest where abundant supplies of sphagnum suitable for use in surgical dressings were early located, but many were made in the East. It was not until the summer of 1918, however, that adequate supplies of raw material were located in the East and the first carload of eastern sphagnum was being loaded (at Old Town, Maine) the day the armistice was signed. Our sphagnum enterprise was one of the many which the abrupt termination of hostilities nipped in the bud.

ADVANTAGES OF SPHAGNUM OVER COTTON FOR USE IN SURGICAL DRESSINGS.

The introduction of the sphagnum as a substitute for cotton in absorbent surgical dressings was not accomplished without considerable protest on the part of Army surgeons. But, although they were objected to on various grounds, the sphagnum dressings gradually won their way, not merely as a necessary makeshift, but on their actual merits; for there seems to be little question that for war hospital work the sphagnum moss is not merely a satisfactory substitute; in many respects, properly made sphagnum dressings are superior to dressings made of cotton.

The advantages of the sphagnum for this purpose are as follows:¹

1. Sphagnum will absorb liquids much more rapidly than absorbent cotton—about three times as fast.
2. Sphagnum will take up liquids in much greater amount than in absorbent cotton. A cotton pad will absorb only five or six times its weight of water, as compared with 16, 18, and even as high as 22 times for a sphagnum pad.
3. Sphagnum will retain liquids much better than cotton, which means, of course, that sphagnum dressings need not be changed as frequently as those made of cotton.
4. The better grades of sphagnum "have the valuable property of distributing whatever liquid they absorb throughout their whole

¹ These observations are taken mainly from Porter, *op. cit.*

mass." An absorbent pad of sphagnum will continue to suck up fluid discharges until it is pretty uniformly saturated throughout, whereas a cotton pad ordinarily ceases to function long before its theoretical capacity has been reached.

5. When properly made, not only are sphagnum dressings fully as soft as those made of cotton, but, owing to the loose, open structure of the moss, they are cooler and less irritating to the patient.

6. In times of emergency, sphagnum can be procured more cheaply than cotton. Being a product of nature, all that is necessary is to go and gather it, and with an abundance of volunteer workers available, practically the only expense involved is the cost of transportation.

Now, in ordinary hospital work, as Professor Porter has pointed out, the comparative inferiority of cotton as an absorbent is not of any great consequence. Here, for the most part, the wounds are the result of operations, and they are made by the surgeon himself. They are comparatively slight, and, what is particularly important, they are perfectly sterile. Discharging wounds are exceptional. For ordinary surgical work it is doubtful whether sphagnum possesses any special superiority over cotton, if indeed, all things taken into account, it is equal to it; and it therefore seems improbable that the sphagnum dressings are destined to come into general use, now that the war is over, except, perhaps, for special purposes. In war-hospital practice, however, conditions are very different, for here every wound may be taken as infected; discharging wounds are the rule, not the exception. Furthermore, "the methods of treatment recently so successfully developed by Carrel, Dakin, Wright, and others deliberately increase these discharges to a very great extent. For such cases, unless absorbent dressings are to be done away with altogether, sphagnum is greatly preferable to any other available material."

RECOGNITION OF SPHAGNUM IN THE FIELD.

The genus *Sphagnum* is classed among the mosses. Unlike the so-called "sea mosses," or seaweeds, and the lichens, which are sometimes mistaken for mosses, the true mosses are leafy plants. Comparatively small, seldom being more than a few inches high, and growing in all sorts of habitats, the mosses are conspicuous chiefly on account of the great masses of vegetation which they commonly form. The sphagnums (pl. 1) include some of our largest and most conspicuous mosses.

Sphagnum differs from other kinds of moss in a number of important respects.

First of all, a sphagnum plant seldom exhibits the deep leaf-green color of an ordinary moss. When wet, it commonly is a pale green;



FIG. 1.—THREE REPRESENTATIVE SPECIES OF SPHAGNUM.

From left to right: *S. fuscum*, *S. papillosum*, *S. Girgensohnii*. The first and last are not suited to surgical purposes.



FIG. 2.—SPHAGNUM OF SURGICAL QUALITY (*S. PAPILLOSUM*).

The specimens shown at the center are the best. From House and Garden Magazine.

when dry, it may be almost white. Very frequently the green is hidden almost completely by pigments of various colors, so that the plants may be almost any shade from bright red and pink to russet green and dark brown or almost black. These colors form a very distinctive feature of many sphagnum when they are fresh; in nature, their mass effect is very striking, and they are of great help when it comes to recognizing material in the field.

But color alone is hardly a sufficient test. Other distinguishing marks are afforded by the peculiarities of the branches and of the leaves. If a single sphagnum plant is examined it will be seen, first of all, that it consists of a main axis, on which are borne numerous short branches. It will be noted, further, that these branches are not borne singly, but in clusters of from three to six. No other moss produces its branches in clusters, after the manner of the sphagnum. Along most of the stem these branch clusters are scattered, but toward the tip they usually grow so close together as to form a rather compact rosette which sometimes is mistaken for a flower. It might be added that the branches in each cluster are of two sorts: One kind stands out at right angles to the main axis; the other kind droops down alongside the stem and forms a sort of loose, spongy matting around it.

And not only is the arrangement of the branches on the stem distinctive. Quite as striking is the arrangement of the leaves on the branches. Every branch is completely covered over by a series of tiny, more or less spoon-shaped leaves, which loosely overlap one another, somewhat after the manner of tiles on the roof of a house.

STRUCTURAL PECULIARITIES TO WHICH SPHAGNUM OWES ITS EFFICIENCY
AS AN ABSORBENT.

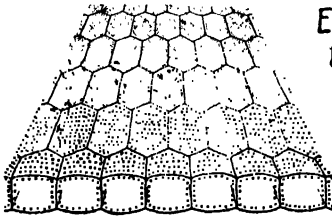
To a limited degree certain of the features already described adapt the sphagnum to absorb liquids—the overlapping of the leaves around the branches, and the sponge-like matting of the pendent branches around the stem. But the real secret of the sphagnum's efficiency as an absorbent lies in the remarkable microscopic structure of its leaves.

Before discussing the somewhat complicated sphagnum leaf, I will describe briefly the much simpler structure of an ordinary moss leaf as it looks under the microscope (fig. 1). Such a leaf consists of a single layer of tiny microscopic cells. Seen in surface view the individual cells are polygonal in outline, but in reality, considered as solids, they are prismatic in shape. All the cells in the leaf are essentially similar to one another; without exception they are green and living, and they are all of approximately the same size and shape.

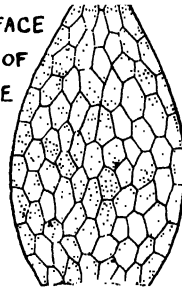
But in a sphagnum leaf (fig. 1) the structure is much more complex. Here also there is just a single layer of cells, but these cells are of two totally different kinds. First, as in the ordinary moss leaf, there are the green, living cells. But these green cells, in the sphagnum leaf, are very small and very much elongated, and they are arranged to form a sort of open network which runs all through the leaf. In the meshes of this network occurs the second kind of cell. These cells are large, without color, dead, and perfectly empty. It is to the presence of these large, colorless cells and to their remark-

A SIMPLE MOSS LEAF

BLOCK SECTION OF
PORTION OF LEAF

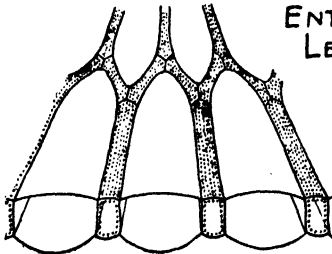


SURFACE
VIEW OF
ENTIRE
LEAF



A SPHAGNUM LEAF

BLOCK SECTION OF
PORTION OF LEAF



SURFACE
VIEW OF
ENTIRE
LEAF

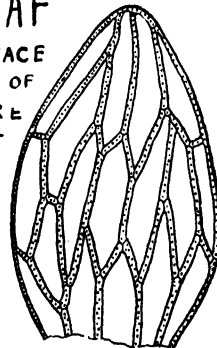


FIG. 1.

able structure, which I shall describe next, that the sphagnum owes its wonderful power to take up liquids.

Now, to a certain extent, the cells of any moss leaf are able to absorb liquids; but the ability of the ordinary green cells in this respect is insignificant when compared with that of the large, colorless cells of the sphagnum leaf. These, because of their capacity for absorption, may well be referred to as the *absorbing cells*. There are two features in these cells which especially adapt them to the function of absorption: First, the wall of each and every one of

the absorbing cells is punctured toward the outside by several minute pores (fig. 2). It is through these pores that liquids are sucked into the cells. Each cell, acting independently, sucks in whatever liquid it comes in contact with until it is full. A sphagnum plant, with its hundreds of leaves, each leaf containing hundreds of these tiny absorbing cells, represents a highly efficient absorbing system. And this absorptive ability is not confined to plants that are fresh; a dry, dead leaf is quite as efficient, when it comes to taking up liquids, as a fresh one. This is due to the second structural peculiarity of the absorbing cells; for inside of each

**DIAGRAMMATIC
SURFACE AND SECTIONAL
VIEWS OF
A SMALL PORTION OF
A SPHAGNUM LEAF
(HIGHLY MAGNIFIED)**

H: LARGE, COLORLESS
CELLS, DEAD, WITH
OUTER WALLS PER-
FORATED (P=PORES),
AND WITH SPIRAL
BANDS OF THICKEN-
ING (T).

G: SMALL, GREEN
CELLS, LIVING, AND
FORMING A NETWORK
WHICH ENMESHERS
THE COLORLESS
CELLS.

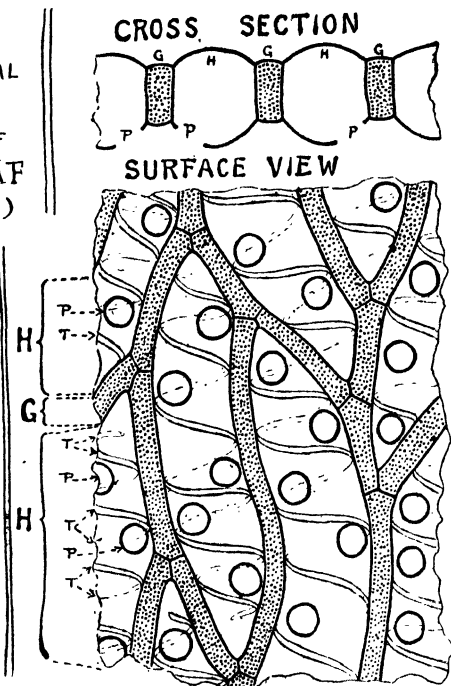


FIG. 2.

one of these cells there is a spiral, spring-like coil of thickening (or commonly a series of hoop-like ribs of thickening) which presses outward, as it were, against the walls of the cell and serves to keep it from collapsing. Even after a leaf has become completely dried out, this "framework" serves to keep the cell cavity open.

Incidentally, while it is the leaves which are most efficient in the absorption of liquids, in some varieties of sphagnum both the stem and branches are enveloped by one or more layers of absorbing cells, essentially similar to those found in the leaves.

It now becomes perfectly clear why it is that sphagnum is so much superior to cotton as an absorbent. In cotton, liquids, for the

most part, are merely held within a tangle of threads. In the sphagnum we find a highly specialized absorbing system, made up primarily of a vast series of absorbing cells, but supplemented to a high degree by various other structural peculiarities of the sphagnum plant.

SURGICAL AND NON-SURGICAL SPECIES OF SPHAGNUM.

By no means all species of sphagnum are of equal value for use in surgical dressings. Failure to appreciate this fact, and the indiscriminate use of any and all species of sphagnum, without doubt, was responsible for much of the dissatisfaction with sphagnum dressings which was expressed by many surgeons in the early days of the sphagnum enterprise. Some species of sphagnum (pl. 1), indeed, are practically useless for this purpose and by far the larger number are of little value. On the continent of North America there are at least 40 different species of sphagnum; in the little State of Connecticut alone there are no less than 25; and of all these there are only 4 that have actually been used to any extent in making surgical dressings. It is not enough, then, to be able to recognize sphagnum as sphagnum. One must be able to differentiate between suitable and unsuitable varieties.

Now, from a botanical point of view, the sphagnums are an exceedingly difficult group of plants to deal with. The accurate determination of specimens is work for an expert. Fortunately, however, the recognition of material suitable or otherwise for surgical purposes is not especially difficult, since all four of the species which are most highly recommended belong to one well-marked section of the genus, the so-called "*Cymbifolium*." group. With a little training and experience it is well within the ability of almost anyone to at least distinguish with some degree of certainty between sphagnum which very likely will prove of surgical value and sphagnum which quite certainly will not.

Without going too much into detail, then, we will consider next just what qualities are desirable in sphagnum material which is to be used in surgical dressings.

First of all, the highest possible capacity for absorbing liquids is essential; and with reference to this qualification there is a wide range of variation between different species. In general, the more robust varieties of sphagnum are better than the more delicate; forms with large leaves, dense foliage, and close-set branches are much better than varieties with small leaves, skimpy foliage, and scattered branches. In the second place, it is essential that the material should be soft and flexible, and at the same time that it should possess a considerable degree of tensile strength. Here, again, there is great variation between different species. In general, coarse or

stringy forms, or forms with stiff or brittle stems or harsh texture, must be avoided.

The qualifications specified above are fulfilled in varying degree by different members of the *Cymbifolium* group. In eastern North America, *Sphagnum papillosum* (pl. 1), to a greater degree than any other species, exhibits the requisite absorbency, softness, and strength and is generally regarded as being much more satisfactory for use in surgical dressings than any other form. Locally, under exceptional conditions of growth, *S. palustre*, *S. magellanicum*, or *S. imbricatum*—especially *S. palustre*—may compare very favorably with *S. papillosum*, but as a rule these tend to develop too much stem in proportion to foliage or have too harsh a texture to make ideal surgical material. In the humid climate of the Pacific Northwest, however, *S. palustre* appears to develop even more luxuriantly than *S. papillosum* and is there regarded as the most desirable species.¹

In the field, *S. papillosum* can usually be distinguished by its very robust habit and its coppery to brownish color; it is never red or purple. The other three species ordinarily are less robust. *S. palustre* commonly is pale greenish white in color; *S. magellanicum* pink or purplish red; *S. imbricatum* green or frequently tinged with brown. These color distinctions are most pronounced in plants exposed to the open sunlight; when growing in the shade all four species are usually green.

In this connection it should be emphasized, not only that different varieties of sphagnum exhibit a wide range of variation when it comes to their capacity for absorbing liquids, as well as in other features which adapt them to surgical use, but also that the very same species may vary greatly in different localities. Growing under certain conditions it may acquire that soft, "bushy" habit so desirable in material which is to be used for surgical dressings, while growing under other conditions it will be harsh, stringy, and quite unfit for surgical purposes. Even *Sphagnum papillosum* exhibits considerable variation in this respect.

GEOGRAPHIC DISTRIBUTION OF SURGICAL SPHAGNUM.

The genus *Sphagnum* is cosmopolitan in its distribution, and all of the species which have been mentioned as being of surgical value are widely distributed in Eurasia, as well as on this continent. In

¹ Mention might also be made here of *S. compactum* which, when well developed, would appear to be even better adapted to surgical work than the forms more generally recommended. This species possesses an unusually soft texture and exhibits a remarkably high capacity for absorbing liquids. Unfortunately, while very widely distributed, it is only occasionally that it is found in sufficient abundance and luxuriance to be of practical value.

general, it can be said that the sphagnums grow best in regions where the climate is moist the year round, and where the summers are not too hot. They develop most luxuriantly near the seacoast, particularly along coasts where fogs are frequent. They are better developed northward than southward.

In North America, *Sphagnum papillosum* ranges throughout much of Canada, extending southward to New Jersey and Wisconsin in the East and to Washington (probably to Oregon) in the West. *S. palustre*, *S. magellanicum* and *S. imbricatum* range somewhat farther south, but, so far as material of good surgical quality is concerned, their geographic distribution may be taken as practically co-extensive with that of *S. papillosum*. The finest development of surgical sphagnum in North America, without question, is in the Pacific Northwest, in the humid strip along the coast from Oregon to Alaska. Hotson¹ even goes so far as to estimate that fully 90 per cent of the sphagnum in the United States, suitable for surgical dressings, is located in the Pacific Northwest. The quality of the material in this region is far superior to that of Eastern moss, and it is from here that most of the sphagnum used by the American Red Cross has been obtained. In the East, sphagnum of surgical quality is extensively developed along the coast from eastern Maine northward; most of the moss used by the Canadian Red Cross has come from New Brunswick and Nova Scotia. Samples of good surgical moss have been seen from southern Michigan and Minnesota, but, on the whole, material from the interior does not compare at all favorably with material from along the seacoast.

LOCAL DISTRIBUTION OF SURGICAL SPHAGNUM.

Taken as a class, the sphagnums are moisture-loving plants; they are hydrophytes. In humid, northern regions, such as coastal British Columbia and Nova Scotia, they are very widely distributed, occurring not only in swamps but on uplands as well. But farther south, in regions where the climate is drier and the summers hotter, they are mostly confined to swamps. The sphagnums grow most luxuriantly and most abundantly in bogs (pl. 2), and this unique type of swamp therefore is worthy of special comment.

Bogs are perhaps most widely known on account of the deposits of peat by which they are commonly underlain, and because of the potential fuel value of these deposits the bogs of this country have been the subject of Government investigations for several years past. Bogs are characteristically developed in wet areas where the soil is poorly drained. Throughout much of the eastern United States most of the areas which to-day are occupied by bogs formerly were

¹ Hotson, J. W. Sphagnum from bog to bandage. Puget Sound Biol. Sta. Bull. 2: 211-247. f. 1-48. 1919.

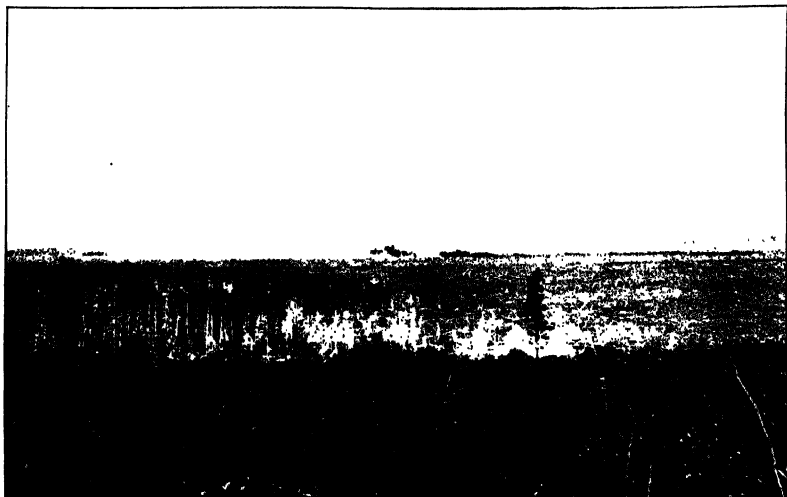


FIG. 1.—RAISED BOG IN EASTERN MAINE.

This bog covers an area of several square miles. From Geographic Review.



FIG. 2.—BOGGY "FLOWAGE" SWAMP IN EASTERN MAINE.

An ideal habitat for surgical sphagnum.

occupied by lakes or ponds, and the same is true of many of the bogs in eastern Canada and the Pacific Northwest. A pond may become filled in and replaced by a bog wholly through plant activity. The filling-in very commonly is brought about through the agency of what is known as a *floating mat*: The vegetation along the edge of the pond grows so vigorously that it spreads away from the shore, out over the open water. In this way there is developed what is commonly referred to as a *quaking bog*. This raft of vegetation, floating on the surface, rising and falling with fluctuations in the water level, may be underlain by clear water or by soft, bottomless ooze. So firm, however, may the mat become that while the surface trembles and quakes when you walk over it, nevertheless it is quite capable of supporting the weight of a man. A quaking bog is an ideal place to look for surgical sphagnum.

Bogs can be distinguished from other types of swamp primarily by certain peculiarities in their vegetation, which in turn are attributable to peculiarities in the soil conditions. In certain respects the plant population of all bogs is essentially similar, no matter what section of the country they occur in. One of their outstanding features is the nature of the bushy element in the vegetation, which, almost invariably, is made up very largely of members of the heath family: Such plants as the bog laurel and bog rosemary, the cassandra, the Labrador tea, and the cranberries. These are mostly absent from swamps of the ordinary description. Bogs frequently are treeless, and when trees are present they are usually scattered and stunted. In eastern Maine an open, bushy bog is commonly referred to as a *heath*; in Europe similar areas are called heath or *moor*.

In the East the characteristic tree of bogs is the black spruce. In the latitude of southern New England this tree is seldom encountered except in bogs, while farther north, where it is much more generally distributed, the dwarfed bog form of it is so distinct from the form that grows on uplands that the two are commonly treated as distinct species.¹ In the Pacific Northwest there apparently is no tree which is strictly comparable in its habits with the black spruce in the East, but bog specimens of various trees, when compared with specimens growing on better-drained soils, appear noticeably impoverished.

From our point of view, however, the most significant feature of a bog is the wonderful development here of the sphagnums. Almost invariably these constitute one of the most prominent elements in the vegetation. To a certain extent the sphagnums may grow in almost any wet, springy swamp, whether it is open or wooded; but even in regions such as Nova Scotia and western Washington, where climatic conditions are most congenial to their development, the sphagnums

¹ See the writer's comment on this point in Trans. Conn. Acad. Arts and Sciences 22, p. 257. 1918.

grow best in the bogs. So abundant, as a rule, are the sphagnums in this particular type of swamp that many bogs are popularly referred to as *moss bogs*.

Bogs do not always originate from ponds. In the Pacific Northwest, in northern New England and eastern Canada, and to some degree in less humid regions, they may develop in flat, poorly drained situations of almost any description, wherever the ground is wet enough to favor the growth of the sphagnums; and in this connection there is one remarkable type of bog that is of particular interest, namely, the so-called *raised bog* (pl. 2). These are met with only in regions where the climate is exceptionally congenial to the sphagnums, for they owe their formation almost wholly to the activity of these plants. The raised bog of North America corresponds to the "Hochmoor" of northern Europe. Sometimes they are referred to as hanging bogs or climbing bogs.

A raised bog may originate on any flat, sphagnum-covered surface where the slope is not too steep. Ordinarily, it starts as a bog of the usual type. The mass of sphagnum, absorbing the water that falls in the form of rain or snow, slowly grows upward, and eventually the mossy surface of the bog, underlain by a spongelike mass of peat, may come to lie 10, 15, and even 20 feet above the original flat substratum. Raised bogs are so termed from the fact that commonly they are much higher near their centers than at their margins, their surface contour, in typical cases, resembling an inverted saucer.

Because of their dependence on atmospheric moisture, raised bogs are confined to regions of copious precipitation and high atmospheric humidity. Their presence in any region is significant, in the present connection, because it indicates climatic conditions suitable to the growth of surgical sphagnum. In Nova Scotia and coastal New Brunswick, where sphagnum of surgical quality is widely distributed, for example, raised bogs are a frequent type. The same is true of eastern Maine. South and west of these regions (in the east), however, raised bogs are practically absent and sphagnum of surgical quality is of very local occurrence.¹ But it should be added, in this connection, that the absence of raised bogs from a region does not necessarily indicate an absence of surgical sphagnum; singularly enough raised bogs are not developed to any extent in the Pacific Northwest,² a fact which I am not prepared to definitely explain. It is further important to note that, while their presence in a region indicates that climatic conditions are congenial to sphagnum development, the raised bogs themselves, except locally in wet depressions, do not afford edaphic conditions suitable to the development

¹ In this connection, see Nichols, G. E., Raised bogs in eastern Maine, *Geog. Rev.* 7: 159-167. *f.* 1-2. 1919.

² See Rigg, G. B., Early stages in bog succession. *Puget Sound Biol. Sta. Bull.* 2: 195-210. *pl.* 29, 30. 1919.



FIG. 1.—BALING SPHAGNUM IN WESTERN WASHINGTON.

From Puget Sound Biological Station Bulletin.



FIG. 2.—PICKING OVER SPHAGNUM AT MCGILL UNIVERSITY, MONTREAL.

From Journal of the New York Botanical Garden.

of surgical qualities of moss; most of the bog surface is too dry. The best surgical material, and by far the largest quantities (this is particularly true of *Sphagnum papillosum*) is to be found in the wet, flat, quaking bogs which border lakes and ponds, and which usually abound in the regions of raised bogs.

PROSPECTING FOR SURGICAL SPHAGNUM.

In surveying any district for surgical sphagnum, there are a few practical points which it is well to bear in mind. A wooded bog may contain plenty of sphagnum, but for our purpose it is rarely of any value. The good moss almost invariably grows in open bogs. Again, an open bog all overgrown with bushes, where the sphagnum forms great soft cushions a foot or so high, is apt to afford pretty poor picking. There may be plenty of moss, but most of it will prove to be of the wrong variety; or if it is of the right variety it will be of poor quality. For that matter, it should be said that in almost any bog there is sure to be a large proportion of undesirable material; commonly the bulk of the sphagnum will consist of species that are of no use at all for surgical purposes.

The best qualities of moss always grow in the wetter parts of a bog. A dry bog is apt to contain no material whatever of surgical value; a wet one may be full of it. The best kind of a bog for surgical moss is a wet cranberry bog: not a bog of the artificial variety that is so common in southern New Jersey, but one where the cranberries grow scattered over a soft carpet of moss, intermixed with more or less "cranberry grass" (*Carex filiformis* and *C. oligosperma*), with perhaps a scanty growth of low bushes. In exploring any bog for surgical sphagnum, always look for the wet places: the soft, quaky spots around the edges of ponds, the mushy depressions, and the wet furrows; and steer clear of the bushy places.

COLLECTION AND PREPARATION OF MATERIAL FOR USE.¹

The moss is usually collected by hand, but in some cases forks can be used to advantage. In collecting, emphasis is placed on gathering clean material, as free as possible from other plants and rubbish, since sooner or later all extraneous matter must be removed by hand. After being pulled up, the moss is squeezed to remove excess water and then packed in a gunny-sack. On some of the Pacific Coast "moss drives" as many as 2,000 sacks of moss were gathered in a single day. If proper precautions are taken against mildewing, the moss, as it comes from the bog, can be stored without injury for

¹ See detailed instructions in papers by Professor Porter (Porter, J. B., Instructions for the collection and preparation of sphagnum moss for surgical purposes. Circular issued by Canadian Red Cross Society. pp. 1-7. 1917) and Professor Hotson (1918 and 1919, *op. cit.*).

several months. Before it is ready to be made up into dressings, however, it must be sorted over (pl. 3) and then dried. In sorting, all foreign material is carefully culled out, and at the same time the moss may be separated into two or more grades. The drying is best accomplished by spreading out the sorted moss in the open air, preferably on drying racks made for the purpose. On account, however, of the obvious difficulties associated with drying large quantities of moss in the open, various methods have been devised for drying it indoors (pl. 4). As soon as it has been properly dried the sphagnum is ready to be made up into dressings.

SPHAGNUM ABSORBENT DRESSINGS.

The simplest type of sphagnum absorbent dressing consists of a cloth bag, which is loosely filled with the moss and then sewed up. The bag is made of light weight muslin of close weave, the usual gauze covering being impracticable on account of its open texture, which permits fine particles of moss to work through and cause irritation. This is the type of dressing authorized by the British War Office. A modification, developed by the Canadian Red Cross, embodies the use of an inner envelope of thin Scot paper tissue to contain the sphagnum, thus permitting the use of gauze for the outer covering. The type of pad developed and adopted by the American Red Cross (pl. 4) is essentially similar to the one just mentioned, except that it has a backing of non-absorbent cotton. In favor of the American type of pad, it is urged that it has the advantage of not becoming quickly wet through to the back. In favor of the simpler types it can be said that, besides being less expensive and less complicated to make, these afford better ventilation, thus being cooler and more comfortable. For certain methods of treatment the American type of pad unquestionably is superior, but "for ordinary cases of infected wounds the straight sphagnum pad, made either with a muslin cover or with gauze and tissue, is in every respect equal to the cotton backed pad:" in fact, in many respects, it is better.¹ Full directions for making the different types of sphagnum absorbent pad are given in the papers by Professors Porter and Hotson, already referred to.

¹ This opinion is expressed by Professor Porter in a recent letter to the writer. He further emphasizes "the especial suitability of the straight sphagnum pad for tropical use and for men who have been burned," as is the case with so many naval casualties.

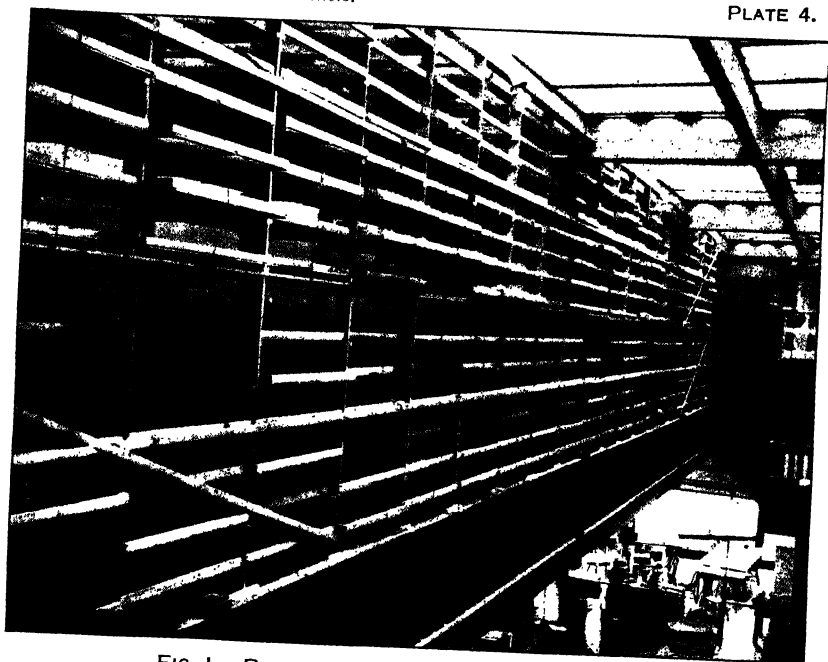


FIG. 1.—RACKS FOR DRYING SPHAGNUM INDOORS.
Red Cross workrooms, Seattle, Wash. From Puget Sound Biological Station Bulletin.

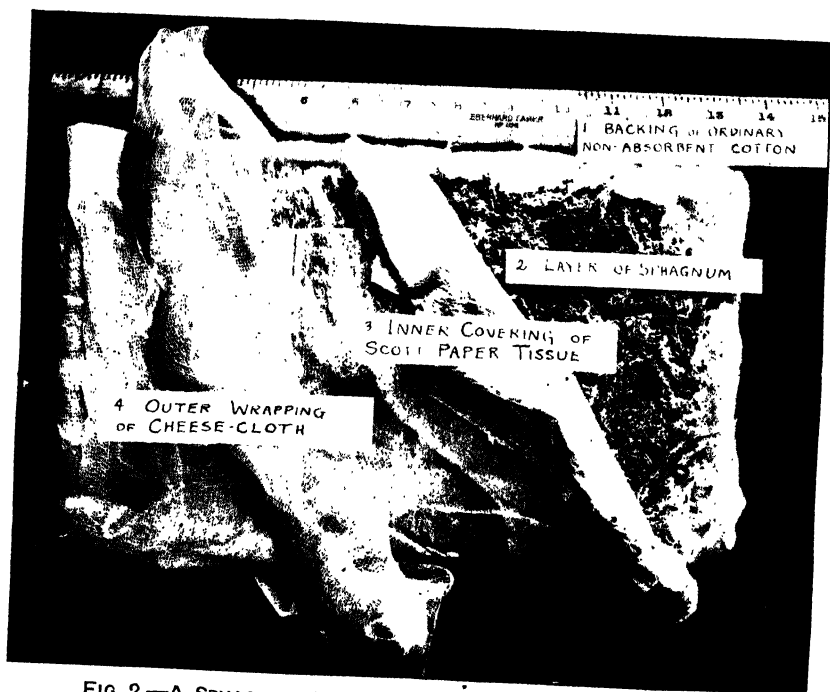


FIG. 2.—A SPHAGNUM ABSORBENT PAD OF THE AMERICAN TYPE.
From House and Garden Magazine.

HISTORY OF MILITARY MEDICINE AND ITS CONTRIBUTIONS TO SCIENCE.¹

By COL. WESTON P. CHAMBERLAIN, Medical Corps, U. S. Army.

I.

The use of arms, however primitive, for offense or defense, must be almost coeval with the appearance of man upon this planet. The carvings of prehistoric races depict the march of organized armies, and from the deepest shadows of history echoes faintly the clash of contending nations. In ancient times the art of war, like other fields of human endeavor, was simple in its practice, victory depending largely upon numbers and brute strength, though the successes of the great commanders of the past, such as Alexander, Pyrrhus, Hannibal, and Caesar, were due in part to superior equipment, and in part to a better grasp by them of the principles of military tactics and strategy. With the increasing complexity of civilization the art of war has not been left behind. Its demands along the lines of equipment, personnel, and brains have steadily increased, and to-day more than ever before, we find in Europe that the latest discoveries in every branch of science, the coordinated energies of the entire nation, and the keenest of intellects are requisitioned to add to the death-dealing powers of the contending races.

While war dissipates treasure, and sacrifices human life by reason of disease and injury, it is the duty of the medical officer to prevent needless wastage of life and limb, first in order to promote military efficiency and secondly in the interest of humanity. *And let it be emphasized at the outset that to-day the first duty of military medicine is not humanitarianism.* War in its essence is both cruel and wasteful, putting the good of the whole above that of the individual, and the military medical service aims primarily to prevent *unnecessary* waste and to remove from the front the inefficient, in order that the supreme commander may have the largest possible number of unhampered fighting men on the firing line. If there is a clash between the welfare of the wounded and the movements necessary for the most efficient prosecution of the conflict, then humanitarianism

¹ Reprinted by permission, from the Boston Medical and Surgical Journal, Apr. 5, 1917.

must give way to military necessity, since victory is the paramount consideration and ultimate success the only complete justification of war. Consideration for the wounded must not be allowed to interfere with the interests of the army as a whole, and it has been said that the commander takes best care of his wounded by annihilating the enemy as promptly as possible.

Like his combatant comrade the military medical officer must bring to his aid, both in peace and in war, every resource known to the healing art. In no other field of professional life is the physician expected to be thoroughly familiar with so many diverse branches of knowledge.

The development of military medicine and surgery began at the same time and kept pace with the slow growth of those arts in civil life. Egyptians, Babylonians, and Hebrews had physicians with their armies, and Sanskrit accounts inform us that thousands of years ago the wounded were removed from the field of battle, and taken care of in tents where beds of leaves were prepared for them. For many ages priests assumed the rôle of physicians in both military and civil practice. Homer tells us that several of the great commanders were skilled in the treatment of wounds, and that a fleet of 30 ships was set aside for the care and transportation of the wounded—the first record of ships being used for that purpose. That the work of the surgeon was appreciated in the time of Homer is shown by the words he put into the mouth of Nestor:

“A surgeon skilled our wounds to heal
Is more than armies to the public weal.”

Homer also lauded the two sons of Aesculapius, both for their skill in arms and for their wisdom in surgery, and thus wrote of them 1,200 years before the birth of Christ:

“Of two great surgeons, Podalirius stands
This hour surrounded by the Trojan bands,
And great Machaon, wounded, in his tent
Now wants the succor which so oft he lent.”

Again he describes an operation performed by one of the surgeons as follows:

“Patroclus cut the forky steel away;
While in his hand a bitter root he pressed,
The wound he washed and styptic juice infused;
The closing flesh that instant ceased to glow,
The wound to torture, and the blood to flow.”

As an example of the practice of a later Greek period, it is stated that Xenophon had eight field surgeons with his 10,000 troops.

During the Roman republic officers of wealth and prominence had their own private surgeons who accompanied them on the march, but

there were no special surgeons for the armies. A regular military medical service dates from the time of the Emperor Augustus. At one period we are told that each cohort of 420 men had four surgeons, while each legion of 10 cohorts had a legionary physician. In the navy there was one physician to each trireme. The physicians were Romans, or naturalized foreigners, and received special instruction for their vocations. At this date hospitals (*valetudinaria*) were established for the severely wounded who were cared for by male attendants. Physicians to Roman legions were of two grades, but commanded little respect, and their standing was on a par with that of the noncommissioned officers. Under the influence of Christianity it became possible to secure more capable surgeons, and non-combatant hospital corps men and litter bearers came into use. Their duty was to remove the seriously wounded to a place of safety, and to care for them, receiving a reward in silver for each man saved. They were required to carry a supply of drinking water and to furnish it as long as the wounded suffered from burning thirst. Each army had a common hospital. The physicians had no executive power and were subordinate to noncommissioned officers.

Abul Kasem, an Arabian surgeon of note living in the latter part of the tenth century, in his work on medicine, devoted to the practice of military surgery a chapter which embodied his own experience on the battlefield. The Helvetians regarded the treatment of the wounded as a sacred duty, but limited its application to their own soldiers, all wounded of the enemy being invariably killed. This practice was sanctioned by many other nations.

After the decline of Rome, armies seem to have been without organized surgical assistance for many centuries. Wounded were removed and cared for by their comrades and by female camp followers. Up to the thirteenth century the practice of medicine was largely carried out by monks, and when this was prohibited by Papal decree, it fell into the hands of the barber-surgeons, who for many years were the only representatives of a sanitary service with combatant units. The names of two military surgeons, Manniot and Nigellus, are recorded in Doomesday Book, 20 years after the battle of Hastings. In 1300 it appears that an effort was made to establish a medical corps in the English Army, but in the muster roll of 1346 no sanitary personnel is mentioned. In 1415, at the battle of Agincourt, there were with King Henry V a physician, a surgeon, and 12 assistants. Physicians, however, were for the nobles, not for the common soldiers. Charles the Bold of Burgundy, in the fifteenth century, is said to have been the first to attach surgeons to troops instead of to officers. Gustavus Adolphus did the same in 1630.

As the healing art slowly developed, a few better educated men came to occupy the higher medico-military positions, but in general there was no organized medical service in armies till about the sixteenth century, and even then conditions were most primitive. Most of the common soldiers with serious wounds were left to die where they fell. If ill or permanently disabled, they were dismissed with a little money to enable them to reach their home. As illustrative of the practices of the times, it is related that Ambroise Paré, the foremost military surgeon of the period about 1550, saw three desperately wounded soldiers placed with their backs against a wall. An old campaigner inquired, "Can those men get well?" to which Paré replied "No." Thereupon the old soldier went over to them and cut all their throats, as the chronicle puts it, "sweetly and without malice." When Paré upbraided him the old campaigner said he prayed God if he were in sickness and pain that some one would do the same for him, that he might not linger in his misery.

The ancient treatment of military wounds was most primitive. For many ages injuries inflicted by swords, lances, arrows, and mace chiefly claimed attention. Arrow wounds were often regarded as poisoned, so treatment by boiling oil was considered by many as most appropriate, and may have had some favorable influence by combating infection. Oil and wine were a favorite remedy for wounds. Arrowheads lodged in the body were drawn out with various crude instruments. Often they were pushed through and removed by incision from the opposite side. In other instances, where less accessible, they were treated by drawing plasters. Rabbits' hair, mill dust, and moss from skulls found in graveyards were used as styptics. Two of the greatest teachers warned surgeons not to undertake an operation, if the life of the patient was in jeopardy, until he had received the last sacrament—a very cheering preoperative procedure. As most of the ancient surgery was practiced by men without education, the literature on the subject is very scanty and unreliable. Clumsy instruments for extraction of arrows were used for centuries without improvement, and ignorance and superstition clogged the wheels of progress.

The introduction of gunpowder, beginning in the middle of the thirteenth century, gradually effected a complete revolution in military strategy and opened up new fields for the military surgeon. The replacing of longbows and crossbows by firearms progressed very slowly, and improvement in the efficiency of these weapons was equally backward. In the unsatisfactory state of surgery in the medieval period, the introduction of firearms brought new dangers and increased the sufferings of the wounded. Fractures of the long bones, previously rare in warfare, became common, together with extensive lacerations of the soft parts. Probes and fenestrated

bullet forceps were gradually introduced. In the fifteenth, sixteenth, and seventeenth centuries the writings show that some still considered such wounds poisoned and treated them by boiling oil, multiple scarification and venesection; while others, especially German surgeons, objected to these cruel methods and resorted to mild measures, such as warm oil of turpentine, hempseed oil, honey and warm milk, especially goat's milk. Tents rubbed with pork to keep the wounds open were advocated. Alum, white hair of the rabbit, droppings of peacocks, dried blood, burning cotton, and red-hot irons were relied on as hemostatics. Suppuration was considered a necessary preliminary to healing.

Amid the barbaric methods, the charlatanism and the superstition of the fifteenth and sixteenth centuries, a few brilliant lights flickered, notably Wurz, a famous Swiss barber-surgeon (1518-1575); Mithobius, who wrote a treatise on military surgery in 1553, and Gelman, who published works on the same subject in 1652. Gelman described a death from tetanus, following a gunshot wound, which he blames on the surgeon, saying that the patient could have been saved if he had been given a draft of Thiriak Andromach in wine of lily of the valley, and if the neck had been rubbed with a particular ointment, and the mouth held open with a gag. The greatest advance in surgery of this period was made by Ambroise Paré (1510-1590), to whom belongs the credit of having brought about the introduction of the ligature, though he himself was not the first to use it. Purman, who wrote an excellent book on military surgery in 1738, is the first to describe deformation of bullets.

In the earliest recorded sanitary organization with armies the barber-surgeons were attached to companies, and a staff physician was assigned to the headquarters of each large force. Regimental surgeons were appointed in the English service as early as 1639 and ranked with chaplains. Sick and wounded were treated in their company camps by camp followers, and when the army moved were carried on wagons or left at the nearest town. In some cases the barber-surgeons provided their own medicines and instruments, while in other instances deductions were made from the men's pay for the purchase of such articles. About the year 1700 medicine chests were provided as a part of the equipment of regiments. In the early part of the eighteenth century the training of a better class of military surgeons was begun and these men were placed in the position of regimental surgeons, supervising the company barber-surgeons. England was one of the first countries to recognize the necessity of a regular medical service in the army and to respect medical officers. From very remote times the medical department was an integral part of the English army, and in 1685 mention is made of a surgeon general, and under William III there was a phy-

sician general, Sir Patrick Dun. In 1751, for the first time, English surgeons were permitted to wear the uniform of the troops to which they were attached, and in 1783 a law was passed prohibiting the sale of the position of surgeon, but this abuse nevertheless continued for a long time. A real medical service in France dates from 1708.

In the seventeenth century military hospitals began to be established in garrisoned towns and in the rear of armies, and to these as bases the wounded were removed. Partly mobile hospitals came into restricted use about 1700, but were not adapted for accompanying marching troops. For many years these hospitals usually carried no tentage and did not reach the field till a day or two after the battle. By a treaty between England and France these hospitals were declared neutral and were treated as such. The Napoleonic wars brought out the amplification of sanitary resources by the use of combatant soldiers detailed as litter bearers and surgeons' helpers. About this same time the barber-surgeons were being generally replaced by trained surgeons, several of whom were attached to a regiment, while medical staff officers were being placed in charge of the sanitary work with armies to coordinate their sanitary resources. Only in 1779 had the barber-surgeons in the British army been given the grade of sergeant, and even then each of them had to expect a whipping if one of his grenadier patients died under his care. Ambulance wagons to transport wounded gradually appeared as a part of the equipment of regiments. About 1810 so-called flying hospitals, able to follow troops, began to be roughly organized. A further great improvement in the type of medical men with the colors occurred, with corresponding improvement in their status. In 1815 Dr. Jackson, who was appointed by the Duke of York physician of all the forces, demanded military honors and decorations for his officers. He said that such titles were irrelevant to scientific men, but that the common soldier would obey the medical officer better if he possessed rank in the army. Jackson's view is as true to-day as in the past, and forms the basis of the present grading and organization of medical departments in all armies. However, in the English service up to 1871, medical officers absolutely belonged to regiments, were exclusively under the control of their commanding officers, and had no powers of command. As a result of our Civil War and the Franco-German conflict in 1870, the importance of increased mobility for sanitary troops was recognized in the British service, the regimental system was broken up, and gradually a medical staff with mixed medico-military titles developed; but its officers were still denied many of the powers which pertained to similar grades in the line. Only in 1898, when the designation was changed to the Royal Army Medical Corps, were British medical officers granted full military titles and most of the accompanying powers which correspond with like grades in combatant branches of the service.

Light field hospitals, able to accompany troops with supplies, surgeons, apothecaries and assistants, came into being about 1850, but these had no organization of litter bearers to bring wounded to them and depended on requisitioned country carts for transport of disabled. The Crimean War demonstrated the inefficiency of the British medical department and emphasized the necessity for some mobile transport organization. As a result litter-bearer sections were organized in several armies. Prior to this the fate of the wounded had been pitiable, though the short range of weapons and close order of battle formation had been factors which greatly facilitated collection and succor of the injured.

Improvements in firearms and munitions, especially rifling and the use of fixed ammunition with conoidal bullets and percussion caps, had caused, at the time of our Civil War, a great increase in the range and rapidity of fire. Tactics began to adjust themselves accordingly. Danger zones increased in depth and the rapidity and precision of the new arms brought about thinning and lengthening of the lines. As a result the wounded were scattered over a much larger area than before. Our sanitary service at that time consisted of several surgeons and a small hospital for each regiment, a fairly mobile field hospital under canvas for each division, a division surgeon to administer the foregoing, and at the bases a great number of vast fixed hospitals. This system was cumbersome and impracticable in that it retained with the regiments seriously disabled men and bulky supplies, neither of which had a place there. It was therefore destructive to tactical efficiency by interfering with the mobility of fighting units. It was undesirable from a humanitarian standpoint because it held sick and wounded at the front where their care and comfort could not be properly considered. The sanitary equipment of the regiments was usually far back with the trains and not available when most needed. The personnel of one regiment might be overwhelmed with wounded while that of another, not engaged, was entirely unoccupied. There were no reserve sanitary organizations for bridging the gap, often very great, which intervened between the firing line and the division hospital, and between the latter and the advance base, or for reinforcing the sanitary services attached to commands which were overwhelmed by a high proportion of casualties. As a result great delays in succoring the wounded and unimaginable suffering occurred in the early part of the Civil War. That these undesirable conditions were not confined to our own Army is shown by the words of an experienced French military surgeon, Le Gouest, who wrote about this time as follows:

Military surgeons who have been present in various engagements all know that when the wounded fall in ranks there are none to carry them off except their own comrades * * * the soldier quits the rank often never to return

or only after the fight is over; the number of men carrying off their comrades is rarely limited to the number really necessary, and one may sometimes see four or five or even six soldiers conducting to the hospital a man slightly wounded and marching as well as his comrades.

It is easily understood how serious to the plans of the commander were such depletions of the ranks in the alleged interest of humanity, but often with the real object of escaping danger. So crippling was the disability under which the sanitary service labored that on August 21, 1862, and again on September 7, 1862, Surg. Gen. Hammond submitted plans for an independent sanitary organization for use with mobile troops. In both instances these recommendations were disapproved by the War Department. In the Army of the Potomac, however, Medical Director Letterman had convinced Gen. McClellan of the need for special aid for the wounded, and on August 2, 1862, he issued an order embodying Letterman's views. His plan, in brief, called for independent ambulance corps for each army corps. This corps was equipped with ambulances and litters, a medicine wagon, and a mounted personnel of officers and sergeants. The transportation was to be used for the carrying of sick and wounded and for no other purpose. No persons except those duly authorized were permitted to accompany sick and wounded to the rear, either on the march or in battle. Subsequently Letterman added plans coordinating the work of the ambulance corps and the field hospital. The advantages of this system promptly became manifest, and it gave admirable service at the battle of Antietam in the month following its inception. Later Grant adopted the essentials of Letterman's plan in the Army of Tennessee, and finally, though very tardily, Congress passed an act, approved by the President on March 11, 1864, establishing a uniform system of ambulance service throughout the military forces. The value of this mobile independent sanitary organization in saving life and suffering, and in promoting tactical efficiency can not be overestimated. The organization and plan worked out by Letterman was so complete and practicable that it remains to-day the foundation upon which the mobile sanitary service in all armies is largely built, though experience has taught that its personnel should be composed exclusively of officers and men belonging to the medical department. With the development of field hospitals and ambulance companies, both being large, independent sanitary organizations, the need of military rank, with authority to command, for medical officers has become more evident, and the subject of sanitary tactics, as an important branch of the art of war, has become an established fact recognized in all armies.

As the organization needful for the handling of the disabled gradually emerged from the neglect and chaos of the middle ages,

so also the practice of military surgery improved coincidently with the progress of surgery in civil life. Intimately associated with the earlier achievements are the names of Paré, John Hunter, and Larrey. The suffering inherent in war was enormously alleviated by the discovery of anesthesia. Still the specter of infection remained, and hospital gangrene was the scourge of the wounded in the Civil War. With the development of antiseptics and asepsis a new era dawned for the military as well as for the civil surgeon. At a somewhat later date the introduction of small caliber, steel-jacketed bullets, which usually produced a small, relatively sterile wound, together with the use of sterile first-aid packets, led to a vast number of healings by first intention in the case of gunshot injuries which had been merely dressed aseptically and then left alone. Asepsis and conservatism were the watchwords, and the saying passed current that the fate of "the wounded man rests with him who applies the first dressing." Much of this optimism has disappeared in the last two years, as a result of the vast European War. The bullet of the latest military rifle is not as humane as that used a dozen years ago. Shrapnel, high explosive shells, hand grenades and bayonets, produce a proportion of wounds far in excess of anything dreamed of in the past. The conditions of trench warfare favor infection, and the great range of modern weapons, and the vast numbers of wounded, have rendered collection of the injured and removal to a place of final treatment far more slow and difficult than ever before. The character of the wounds produced by shell, shrapnel, hand grenades, and spitz bullets is such that the first-aid dressing has failed to confer as high a degree of protection as it afforded in the wars of the previous two decades. Asepsis is less in vogue, and in England the cry has been raised, "Back to Lister"—in other words, antiseptics with strong disinfectants like pure phenol. Extensive opening of wounds with free drainage has replaced expectant and conservative treatment. No longer is it said that the fate of the wounded rests with him who applies the first dressing, but rather that his future depends upon the rapidity of transportation and the possibility of thoroughly treating his wounds as soon as possible by elaborate surgical procedures.

Turning from the field of surgery and relief organization in battle, we find that military medicine, as distinguished from surgery, is intimately associated with, and a decided contributor to, the subject of preventive medicine. Since the days when "The Assyrian came down like a wolf on the fold" armies have been peculiarly the victims of epidemic diseases. Numberless campaigns have failed in whole or in part, because of dysentery, cholera, plague, scurvy, measles, small-pox, yellow fever, malaria, typhus, or typhoid. An interesting review might be written dealing with history as influenced by epidemic disease. Up to the time of the Franco-Prussian War in 1870, disease

had always claimed far more victims in every campaign than had the bullets of the enemy. With the growth of the knowledge of infections during the last half century, the control of diseases due to preventable causes has become one of the paramount duties of the military surgeon, and the success he has attained is shown in the remarkably great decrease of sickness in the Russo-Japanese War, and in the present war in Europe, as compared with campaigns of the past. In our own service three great triumphs stand forth—the eradication of yellow fever in Cuba, the prevention of beriberi among Philippine troops, and the suppression of typhoid fever through our entire Army by antityphoid inoculation.

Looking back a little more than a century and a half the eye is caught by the name of Sir John Pringle (1707–1787), who is called the founder of modern military medicine as contrasted with surgical practice. Pringle, a Scotsman, served on the continent in the mid-century wars and was surgeon general of the English Army from 1742 to 1758. His work, "Observations on Diseases of the Army," 1752, promulgates the true principles of military sanitation, especially in regard to the ventilation of hospitals, ships, jails, and barracks. He gave a good description of typhus fever, showed that jail fever and hospital fever were the same, correlated the different forms of dysentery, and named influenza. About six years later appeared Van Swieten's monograph on camp diseases, and two works on the hygiene and diseases of sailors by James Lind and Thomas Trotter. Both of these physicians published monographs on the subject of scurvy, which came into great prominence through its ravages among the sailors of Lord Anson's expedition in 1740.

No review of the history of military medicine would be complete without the mention of some of those military medical men whose names should always be held in memory because of notable services to the cause of progress and humanity. The civilian is apt to think that the duties of the medical officer are light and routine, and that his professional work consists largely in treating venereal diseases. Far otherwise. His life is a busy one, entering into practically every field of medicine, in many of which he delves so deeply that he unearths nuggets for the use of future generations. The first name I will mention is that of Ambroise Paré, born in 1510, the great French military surgeon whose fame particularly rests on the substitution of the ligature for the actual cautery and the styptic relied upon before his time for the control of hemorrhage. He was not the first to use the ligature, but to him belongs the credit of having led to its general introduction against great opposition. He combated the prevailing opinion that gunshot wounds were poisoned. He opposed the use of boiling oil, popularized the use of the truss, introduced massage, artificial eyes, and staphyloplasty. He described fracture of the neck

of the femur, and was the first to suggest syphilis as a cause of aneurysm—a goodly contribution for one who began his career as an apprentice to a rustic barber. His first military patient was a captain shot in the ankle. Paré says of this case, "I dressed him and God healed him." As he passed through campaign after campaign his reputation became more firmly established among both soldiers and physicians. When he entered Metz, which was being besieged by Charles V in 1552, and was dramatically presented to the officers by the Duke of Guise, he was received by the soldiers with shouts of triumph and the exclamation, "We shall not die even though wounded, for Paré is among us."

John Hunter, the erudite scholar and great surgeon, was a staff surgeon in 1761, when he gained his unique knowledge of gunshot wounds. His contributions to surgery are too well known to need mention. He was made deputy surgeon general in the British Army and introduced a system of promotion in the medical service.

The name of Baron Larrey is ever associated with the campaigns of Napoleon, and he was one of the great Emperor's intimate friends and most trusted advisors. His energy on the battle field and his genius for organization have never been surpassed. His flying ambulance corps and mounted surgeons often passed through showers of bullets in bringing aid to the wounded. At Aboukir Bay he amputated General Sully's leg above the knee under fire, and carried this officer to safety on his own back just in advance of a charge of British cavalry. He was an able surgeon and the first, in spite of strong opposition by civil surgeons, to advocate the employment of plaster splints in the treatment of gunshot fractures. In fractures of the leg, he used them to allow the patient to leave his bed as soon as possible. His military service extended over 50 years, and he participated in 26 military expeditions in three continents. Probably under no circumstances did the ability and courage of this remarkable man show to better advantage than during Napoleon's retreat from Moscow. After the battle of Borodino, Larrey made 200 amputations, practically with his own hands, with no bed or shelter, cold so intense that the instrument often fell from the benumbed fingers, and with the Cossacks hovering around equally ready to kill patient and surgeon. At the battle of Waterloo, he was sabred by Prussians and left for dead. Recovering consciousness and trying to make his way across France he was captured, robbed, and sentenced to be shot. A Prussian surgeon, who had attended Larrey's lectures several years before, recognized him, and the order of execution was stayed by Marshal Blücher, whose son had been saved through Larrey's exertions when wounded by the French in the Austrian campaign.

The greatest of Russian surgeons, and one of the greatest military surgeons of all times, was Nikolas Ivanovich Pirogoff, born in 1810, and who, like Paré and Hunter, had a remarkable career of self-development. He served in the Caucasus in 1849, in the Crimea in 1854, and also reported on the Franco-Prussian and Turco-Russian campaigns. He defined war as a "traumatic epidemic." He introduced female nursing of the wounded in the Crimea and was a warm advocate of freedom and higher education for women. In his treatise on military surgery, published in 1864, he holds large hospitals responsible for the spread of epidemic disease, and recommends small pavilions and segregation. His method of complete osteoplastic amputation of the foot is well known to all surgeons.

Friedrich von Esmarch, the great German military surgeon, introduced the first-aid dressing and standardized surgical hemostasis by the Esmarch bandage. He did much to improve the status of military surgery and the first-aid treatment of wounds. By marrying a royal princess he became uncle to the present Kaiser. Turning from the realm of the wounded we find that Emil von Behring, whose name is ever associated with antitoxin, began his career as a Prussian army surgeon. In 1880 the epoch-making discovery of the malarial plasmodium was made by Alphonse Laveran, a French army surgeon. The importance of the discovery of plasmodium was equaled by the demonstration of mosquito transmission made by Ronald Ross, a surgeon in the Indian Army Medical Service. After years of patient work he was able to trace the full development of an avian parasite in culex and partly that of the human malarial parasite in anopheles. Ziemann, a naval surgeon, was the first to confirm the work of Ross and the Italian observers. More recently much important and original work on malaria, as well as on entamoeba, has been done by Capt. Charles F. Craig, of our own medical corps, who has written several monographs on these subjects. Capt. Craig, in association with Maj. Percy M. Ashburn, was the first to establish the truth of Graham's theory that dengue fever is transmitted by the bite of mosquitoes of the genus culex.

Our knowledge of tropical medicine was enormously advanced by Col. Sir W. P. Leishman and by Maj. Charles Donovan, both of the British service, who independently discovered that the so-called dumdum fever, or Kala-Azar, was due to an intracellular parasite, which has been named, in honor of its discoverers, *Leishmania donovani*. The name Col. Leishman is also associated with one of our well-known polychrome stains.

Other names intimately associated with tropical and preventive medicine are those of the naval surgeons Mormand and Bovay, who first described the parasite of Cochin-China diarrhea; Maj. Bailey K. Ashford, of our Army, whose work on hookworms in Porto Rico

is too well known to need description; Capt. E. D. Vedder, who in my laboratory in Manila performed the experiments with emetin and amoeba, which led Leonard Rogers to undertake the hypodermic treatment of amoebiasis with that drug. Capt. Vedder and myself in Manila carried out extensive investigations on beriberi, and were the first to show that the extremely fatal infantile beriberi was promptly curable by the use of an extract of rice bran or polishings. While the English and the Germans were the pioneers in developing the antityphoid inoculation, it was through the enthusiasm and energy of Maj. F. F. Russell, of our medical corps, that the practice was introduced and made compulsory in the United States Army. Our service was the first in which compulsory antityphoid vaccination was employed, and the demonstration that the scourge of armies could be eradicated as a result of this measure stands as one of the greatest triumphs of preventive medicine.

Among others in our own service whose names will be remembered should be mentioned Gen. George M. Sternberg, formerly Surgeon General of the Army, and who has but recently died. Sternberg was a pioneer in bacteriology in this country, and his book on that subject was for many years a standard work of reference. He was particularly interested in the subject of yellow fever, and it was due to this interest that the board of Army medical officers was appointed which disclosed the method of transmission of that disease.

Among those members of our Army medical service who subsequently became prominent because of work outside the practice of medicine and surgery may be mentioned Maj. Gen. F. C. Ainsworth, who was for many years Adjutant General of the Army, and Maj. Gen. Leonard Wood, a graduate of Harvard, who for high executive ability has been promoted to many important posts. Col. John Shaw Billings has been pronounced by competent authority to be the most eminent bibliographer in the history of medicine. He served with great credit as surgeon through the Civil War, and in 1864 was transferred to Washington for duty, where he remained till his retirement in 1895. His name is indelibly associated with the upbuilding of the Library of the Surgeon General of the Army, which through his energy became the largest medical library in the world, and also with his index catalogue of this library. With Fletcher he edited the *Index Medicus* for 20 years. The trustees of the Johns Hopkins fund in 1876 elected him as their medical advisor after having accepted his designs for the Johns Hopkins Hospital as the most satisfactory of any submitted. In 1896, one year after his retirement from active service, he became superintendent in chief of the New York Public Library, where he solved the enormous difficulties connected with the consolidation of the New York libraries and the

construction of the present magnificent building. He remained with the library until his death in 1913. In 1905 he was selected to lay out the plans for the Peter Bent Brigham Hospital now facing the Harvard Medical School.

The name of Jonathan Letterman should always be remembered by military surgeons as the greatest sanitary organizer of modern times. I have already referred to his plans for an ambulance corps which became the basis for such service in all armies. He put an end to the depleting of the ranks of the Army which had been caused by injudicious and careless discharges for disability, and by the license of sending to distant general hospitals men who should never have left the zone of operations. He insisted on having sick and wounded treated at hospitals nearer the front whenever the condition of the service and the welfare of the patient permitted, thus doing away with one of the chief factors in military absenteeism. By well-thought-out sanitation, strenuously enforced, he kept the Army of the Potomac in a state of health unparalleled in forces of such magnitude at that time. For alleviating the sufferings and saving the lives of thousands of his countrymen, and for adding to the vigor, discipline, and effective fighting strength of the principal army of the Republic, he has a just claim to the grateful remembrance of his professional brethren, of his comrades in arms, and of his countrymen. Gen. McClellan wrote of him in 1863, "I never met with his superior in power of organization and executive ability." His name is now commemorated in the Letterman General Hospital at the Presidio of San Francisco.

The most distinguished and important internist of the early French school was René Laennec (1781-1826). Like Bichat, the creator of descriptive anatomy, he was a regimental surgeon in the French Revolution. Both were early victims of phthisis. If we can trust Kipling's description, it was while a military prisoner in England that Laennec carried out the experiments with the stethoscope, the instrument with which his name is indissolubly connected.

Intimately associated with the Post of Plattsburg Barracks, from which I have recently come, is the name of an Army medical officer at whose door opportunity knocked and was not refused entrance. Dr. William Beaumont, by his observations and experiments on the Canadian half-breed, Alexis St. Martin, laid the foundation for our present knowledge of gastric digestion. Part of this work was carried out at the isolated military post of Mackinaw in the primeval forests of Michigan about 1825, and the remainder of the investigations were conducted at Plattsburg Barracks, N. Y. Beaumont was the true leader and pioneer of experimental physiology in our country. His work remains a model of patient, persevering investigation, experiment, and research.

The conquest of yellow fever is a far-reaching achievement to which America can lay entire claim, and which especially reflects credit upon the Medical Corps of the United States Army. In 1900 the Army board, consisting of Maj. Walter Reed, Maj. James Carroll, and Contract Surgeons Lazear and Agramonte, proved by a series of brilliant and conclusive experiments that yellow fever is transmitted by the bite of a mosquito, the *Stegomyia fasciata*. Basing his sanitary work on the discoveries of Reed and his associates, our present Surgeon General, William C. Gorgas, freed Cuba of yellow fever and made possible the building of the Panama Canal, thereby establishing his claim to be called the greatest sanitary expert the world has known.

The experiments which established the mosquito theory of yellow fever transmission are so recent and well known that I shall not enter into them except in one particular. Dr. Lazear died from yellow fever contracted while at this work. Acting Asst. Surg. Robert P. Cooke and several volunteers from the Hospital Corps slept for 30 nights in a small unventilated room, using the bedding and wearing the garments just taken from fatal cases of yellow fever and which were soiled with the black vomit and excretions of these patients. Maj. Carroll first, and subsequently several members of the Hospital Corps, submitted to the bites of mosquitoes which had previously fed on yellow fever victims. Several of them contracted the disease, and Maj. Carroll narrowly escaped death. The world at large recognizes that it requires high courage for the soldier to charge the enemy, even in the excitement of battle and surrounded by his comrades. In the present European war hundreds of medical men have met wounds and death in serving the cause of fatherland and of humanity under fire. It called for courage of a different quality, but of quite as high an order, to enable a man to submit himself, in cold blood, for experimental infection with a disease which was as mysterious, as painful, and as fatal as yellow fever. All honor is due Maj. Carroll, Dr. Cooke, and those Hospital Corps men who stood this test in the interests of humanity and to the everlasting credit of military medicine. There is no better example of the sentiment that "Peace hath higher tests of manhood than battle ever knew."

SOME PROBLEMS OF INTERNATIONAL READJUSTMENT OF MINERAL SUPPLIES AS INDICATED IN RECENT FOREIGN LITERATURE.¹

ELEANORA F. BLISS,

Associate Geologist, U. S. Geological Survey, Washington, D. C.

INTRODUCTORY.

During the four years in which the greatest nations of the world have been locked in a struggle for military supremacy, there have been many thinking men both behind the fighting lines and within the camps of the belligerents who have realized the rôle played by economic and commercial activities in the evolution of that international status that was inevitably bound to result in the most terrific human explosion that has been witnessed in the history of mankind.

It is a fact that nations, while in truth forming one great world family, yet are and always will be actuated by the same individual interests and selfish desires that are bound to be an actuating principle in the lives of those who make up any human family. By realization and appreciation of the fact that as in a family, human equity demands the recognition and development of the rights of the individual, so in the world international justice and polity demand the right of individual nations to the means of sustenance and growth, we shall arrive at a conception of the much longed for "world democracy."

In practice this right can not be actually attained. By virtue of circumstances certain individuals and nations are more highly endowed than others with nature's gifts. While the ideal of democracy that all men are and of right should be free and equal, may, and doubtless will, remain to the end of time unattainable, yet the principle of democracy as rightly and faithfully applied demands that those individuals or nations who have attained a certain supremacy in the affairs of mankind shall watch over the welfare and safety of those who must struggle under the handicap of a lesser share of nature's endowments. In the life of a democratic state there will always be two factors that will combine to keep the

¹ Reprinted by permission from *Economic Geology*, Vol. XIV, No. 2, March-April, 1919.

balance true and to prevent the undue ascendancy of one individual to the exclusion and to the undoing of others. They are: first, the disinterestedness of human nature which has led many a man to give up not only his life but also the chances of so-called personal aggrandizement for the sake of benefiting other individuals and the race at large; second, the self-interest of human nature which leads every man to struggle against those interests and ascendancies that he conceives to be prejudicial to his own personal welfare. It is only by a true appreciation of these two predominant influences in the lives of nations and mankind that we shall be able to exercise the curb in international relations that is of paramount importance if we are to prevent a repetition of the struggle of the past four years.

GERMANY'S METHOD OF COMMERCIAL EXPANSION.

A clear exposition of some of the conditions and policy that led up to the recent war is shown in a book published during 1918,¹ "Germany's Commercial Grip on the World," by M. Henri Hauser, a professor in the University of Dijon. It was written in order to bring to the French-speaking public the realization of Germany's business methods as applied to her foreign trade, the business methods by which she had acquired before the war a commercial ascendancy, little realized by the average business man in countries not apparently within the sphere of German influence, and completely unappreciated by the unsuspecting consumer, who regarded the trade mark "made in Germany" with an amused toleration frequently bordering on contempt.

Hauser's book is a distinctly fair and unbiased attempt to set before the mercantile and also the lay reader the means by which Germany had made for herself that domination in the commercial world which is the undoing of all real international democracy. He gives due credit to German economic virtues, such as her increase in population, her industry, her discipline, and her submission to authority. In his analysis he emphasizes four fundamental instruments in the attainment of German commercial power: the bank system, the cartel, the transport organization, and the rôle of the state in encouraging and supporting specialized industries.

The bank system.—By the combination in German banks of the three functions of deposit, credit, and finance these organizations have been enabled to play a part in the promotion of industrial enterprise which in our own country is reserved for the individual financier, for the banker rather than for the bank. In order to render their export trade independent of British and French financial channels, the various large German banks began, as Hauser aptly

¹ Hauser, Henri, "Germany's Commercial Grip on the World," Scribner, 1918.

phrases it, to "swarm" and in a comparatively short time a network of German banks was established in South America, Italy, Greece, Turkey, and Asia Minor. The dangers attendant upon such a wholesale participation of the banks in industrial promotion resulted in some heavy losses and caused the banks to adopt a system of grouping by which each great bank supports several undertakings and on the other hand each large financial enterprise is backed by a group of several banks. This grouping of banks is rendered possible by a mutual interchange of paper, a method which however advantageous from the point of view of business promotion is nevertheless susceptible of most dangerous collapse in the event of sudden slump. The relation of the original German bank to the home industry is reproduced in the relations of the subsidiary foreign banks to the importer and exporter. They supply the manufacturer with credit that enables him to furnish his customers with the particular type of long-term payment best suited to their convenience. Moreover, the practice of gradually withdrawing German capital from overseas banks after the institution had been successfully manipulated into German control has resulted in the financial domination of foreign countries without the locking up of home capital to any large extent. The loans made to a foreign state are repaid in orders, insurance companies instituted abroad replace their reserves in German securities; in short, the trend of capital is all towards Germany. Such a condition of affairs leads to what even a German was forced to characterize as "an unhealthy rise in industry" and furnishes the possibility of a phenomenal and predominating industrial expansion.

The cartel system.—The celebrated cartel system to which Germany owes so much of her industrial efficiency is characterized by Hauser as a combination of producers for the cooperative sale of their output or of certain classes of their output. It differs from our trusts in that the individual enterprise retains its entity, but shorn of all independence in the sales transaction which is either carried out by the sales bureau or else regulated as to price, geographic limitation, quota of production by individual factories, etc. There are two factors which check the domination of the cartel. The larger establishments, such as Krupp, escape its domination because they are able through their far-reaching interests to supply themselves with all the essentials of their industry within their own domain. Moreover, the changeable nature of the cartel which adapts itself to and changes with the condition of the market renders it not so much an ironclad yoke as an adjustable harness by which competition is restrained, overproduction regulated, and lowering of prices prevented, provided the adherents of the cartel submit to the rigid discipline of its authority. Hauser explains how the

cartel came into being as the inevitable outcome of the period of overproduction, under consumption, and lowering of price that accompanied and followed the financial depression of 1873. At that time competition was so intense as to be well nigh the extermination of many industries and the cartel, which was instituted more or less as a self-protective measure, has later by its introduction of "dumping" on foreign markets been enabled to control and correct the conditions in the home market that have always been both a stimulus to German industry and a menace to foreign competition, namely, the ability of the German factory to overproduce. By "dumping," the German manufacturer gets rid of his surplus production on the foreign market at a price that would be disastrous were it not for his ability to rehabilitate himself by means of the higher domestic price set and maintained by the cartel. Through the cartel he is also enabled to acquire an export bonus on the price of raw materials destined for ultimate export in the form of finished product.

Transport.—Additional facilities are furnished to the export trade by the special transport rates on both railway and steamship lines which not only enable the manufacturer to get his goods to foreign destinations at sometimes only one-quarter more than he would pay to ship the same commodity between Breslau and Hamburg, but also offer an attraction to foreign shippers to consign their merchandise via German railways or German ships at greatly reduced freight charges. In other words, by means of the State operation of railways the Government is enabled to practice a sort of railway dumping by which the transport charges can be reduced for the benefit of the export trade or of foreign traffic.

Rôle of State.—M. Hauser emphasizes the function of the German State in economic domination through its ownership of railways, and its military and naval consumption, together with its hold on the electrical industry acquired by its monopoly of canal towage.

In regard to the cartel the State finally resolved to make a virtue of necessity by adopting a policy of toleration and supervision which wound up in some cases by the State absorbing the cartel as in the case of the loose jointed union between the government and the coal syndicate, or by the State organizing the cartel as in the case of the potash syndicate, which owed its existence in the first place to the desire of the Government to regulate the production of the Prussian Stassfurt mines and to keep the price sufficiently high to preserve for the nation the material required for agriculture. The potash syndicate holds a unique position among German cartels owing to the fact that German potash production has resulted in the largest national monopoly known among minerals. The aim of the Kali-syndikat was not to encourage export by reduction in prices on the foreign market, but rather to raise the export prices and thus by a system of reverse dumping to reserve material for home consumption.

Conquest of foreign markets.—In the last section of his book Hauser deals rather briefly with German methods for conquest of foreign markets. He emphasizes the systematic study of the individual market and clientele by which the German exporter arrives at a complete understanding of the requirements and possibilities of their export business. He notes the acumen and psychological shrewdness of the German commercial traveler who is constantly on the spot, always anxious to satisfy his customer, always ready to do business honestly if possible, dishonestly if necessary. He calls attention to the exportation of a business house where it seemed that foreign trade could be better handled through the direct management of an overseas branch of the German industry, and he laments uncontested intervention of the German middleman in the conduct of French trade. He acknowledges the cleverness of German propaganda and publicity methods by which they handle an enormous and skillfully manipulated self-advertising scheme. Most important of all, he explains the final step in German exportation, which is the transplanting of factories themselves into foreign territory. He disposes of the fallacious argument that such export of industry enriches the country so penetrated by showing that, as in the case of the foreign branches of German banks, capital is not actually transferred from the German source to the foreign country, but on the contrary the minority of the share of capital is frequently the German portion. Nevertheless, the German skillfully manipulates the distribution of interests so as to retain a controlling hand in the management, and in addition he obtains a corner on the foreign raw materials in which he is often deficient at home. A good example of this was the Thyssen control of Normandy blast furnaces through his institution of a factory and railway in association with the iron mines in Normandy. In return for his cession of all except 20 per cent of his control of the factory to so-called French interests he acquired the right to purchase the complete supply of the Norman furnaces. The last step in exportation is taken in order to escape burdensome taxes on finished products, machinery, dyes, etc., and the German exports his semifinished materials and assembles and perfects them in the country of their ultimate destination.

Economic factors in causing war.—In conclusion Hauser sums up the conditions which were potent factors in causing the recent war—first, the sudden and daring rise in German industry that has necessitated the organization of a drastic cartel system to combat the dangers of unlimited competition entailed by overproduction; second, the further relief of this congestion of overproduction by means of an overdeveloped system of foreign dumping; and, third, the temptation to stabilize her somewhat shaky financial foundation

by the accession of foreign capital which it was becoming increasingly difficult to attain by peaceful methods. In short, Germany's commercial grip on the world, which had strengthened speedily and yet to a large extent unobserved, had finally reached a point where its future strength was becoming imperiled by the growing realization of other nations and their consequent restlessness under the yoke. Such an autocratic and ironclad policy can not continue forever unchallenged, because there exists in the world that inherent democracy of nations, perchance actuated by fundamental self-interest, which at all costs insists upon maintaining to individual nations the right to exist.

The Russian opinion of German methods is briefly set forth in a small volume by Dr. Paul Gourvitch¹ written in English and published in New York in 1917. It is also a fair and unbiased description of German commercial power. It gives due credit to the fact that much of her supremacy was due to her own energy and foresight in the conduct of her exporting business by which she was often enabled to supersede the laxer and more "hit-or-miss" methods of her foreign competitors. Gourvitch describes in detail the importing and exporting of credit. While giving due credit to German skill and enterprise in the manipulation of foreign markets he does not fail to note their dishonest and unscrupulous methods in the matter of imitation and counterfeiting in order to replace the commodities of their competitors by their own goods sold at lower prices.

GERMAN POSTWAR TRADE.

The volume by Herr S. Herzog,² which was published in translated form about two months ago under the auspices of Herbert Hoover, Vernon Kellogg, and Frederic C. Walcott, called "The Future of German Industrial Exports," represents the ideas of a well-known German engineer on the subject of reestablishing after the war the same methods of commercial supremacy that led to the recent catastrophe. His avowed aim is to regain by strategic means the former commercial position of Germany. He definitely states that since the par value of treaties is nil, any commercial treaty formulated after the war will be worthless. He contends that the treaty will be but the preliminary to an economic warfare having for its object the mastery over German industry. He states that Germany's industrial exports must go on. In order to do this the essential structure of German industry is to be divided into two classes, the first known as "protective industries," representing both raw and finished products of German origin that are absolutely

¹ Gourvitch, Paul, "How Germany Does Business," B. W. Huebsch, New York, 1917.

² Herzog, S., "The Future of German Industrial Exports," Doubleday Page & Co., Garden City, New York, 1918.

indispensable to some foreign country. These products are to be placed under a special State control by which they are to be fostered and supported so that it will be possible without killing the industry to place an absolute embargo upon its market in any foreign country that has shown injurious discrimination against Germany. The second class comprises those auxiliary industries that furnish to the protective industries the necessary raw materials. These auxiliary industries are obliged to furnish the necessary raw materials at such low cost that it is possible for the protective industry to remain always in control of the market. The secondary industry will be reimbursed in the course of time by a percentage share in the earnings of their customers or else through the general guarantee fund which it is proposed to institute in order to supply the necessary reserve capital that will enable the protective industries to cut their prices below competition and to submit to embargoes on their market while they produce a stock surplus. It was also proposed to institute a central sales bureau that should have complete charge of the foreign sale or embargo of the output of the protective industries.

His scheme as elaborated is chiefly a matter of domestic organization which had already reached such an advanced point in German industry. Its weak point is that Germany is dependent for many raw materials upon foreign sources. But it must be remembered that this book was written in the confident expectation of a complete German victory by which she would be in a position to dictate her terms to the world. What these terms would have been is stated in Chapter II with a candor for which we can not help but be grateful since "forewarned is forearmed." The terms of their commercial treaty would have entailed assurance of raw materials at suitable prices, prevention of specially discriminating or injurious foreign tariffs, assurance of all concessions and protection to German interests that are conferred upon any other nation, and official recognition of the various federations that were to furnish the modus operandi of the schemes outlined above (for the protection of German interests). Herzog then goes on to indicate that it would be well to demand exclusive favoritism of Germany in certain points, after carefully eliminating all possibility of any discriminative favoritism against Germany. He demands for her unlimited right to secure raw materials abroad without any export restriction in the country of origin, he insists upon the right of supervision over German plants abroad that are furnishing raw materials to the protective industries, he stipulates for control of foreign freight rates, he eliminates all foreign concessions that could benefit other countries to the exclusion or disadvantage of Germany, and he demands a special guarantee to cover German capital invested in foreign countries. In

short, he demands not only an open door for German trade but also all kinds of special provisions operating to the benefit of German trade in order that she may entrench herself safely behind an invincible bulwark of commercial supremacy.

READJUSTMENT OF MINERAL SUPPLIES.

A commercial domination by any one nation is obviously unjust and is as we have seen one of the most potent reasons for the recent war. We can not escape from the fact that in the interrelation of nations, certain countries are bound to play a dominant part in the production or in the manufacture of certain commodities. The German control of potash and the Chilean output of nitrates are the largest examples of so-called world monopolies of minerals. Nevertheless, in the last four years even these two most formidable commercial bogies have been robbed of some of their terrors.

Potash.—We have found to our surprise how possible it is for us to get along without German potash. The possibility of decreased consumption, various new sources as well as the increased possibility of recovery from waste sources in blast furnace and cement plant gases have shown that for a considerable period, at least, we are not absolutely helpless without the German supply. But commerce, which takes the place in the life of a nation that breathing does in the life of an individual, must, in order to attain eventually the best results, be like breathing, a natural process.

In the present stage of the world's development the natural source of supply for potash lies in the German deposits and from that supply we have a right to expect our maintenance. It is a debt that Germany owes to the democracy of nations and which she must pay with equity and, if not voluntarily, then under protest. In this connection it should be noted that the reserves of Alsace-Lorraine have been computed as sufficient to furnish the world with potash for 300 years; have been considered to be about equivalent to those of the Stassfurt deposits, while it appears likely that reserves of considerable magnitude may be developed in northeastern Spain. So much for potash, which, though important by reason of its entire localization within the confines of what was German territory, is not one of the most essential of mineral commodities.

The important mineral commodities.—The accompanying figures show in diagrammatic form the relative control by the United States, Great Britain, France, and Germany of the five most important mineral commodities. The first column represents the percentage of the world's output that is produced by these countries and by their colonial possessions. The second column represents the production control of raw material exercised by these four countries, as expressed by their domestic production plus their imports. The third column represents the consumption control of finished products

as expressed by the amount of raw material retained in the country after export.

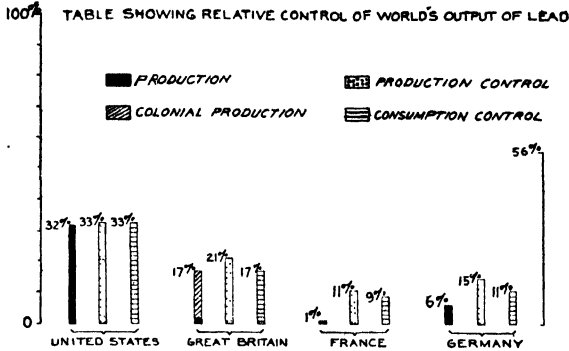


FIG. 1.

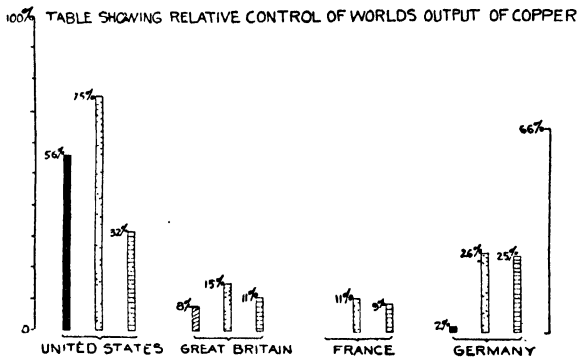


FIG. 2.

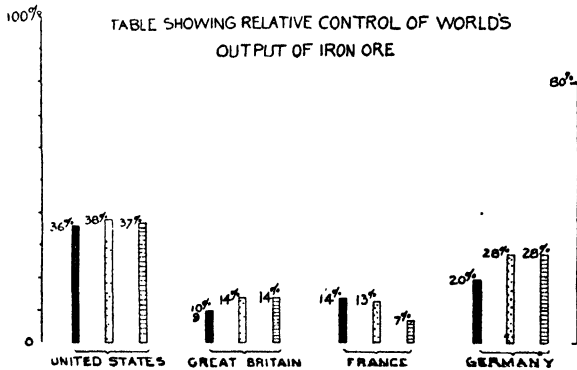


FIG. 3.

FIGS. 1, 2, 3.—Dominant control of the world's output of lead, copper, iron-ore of mineral products. Aggregate control shown by vertical line on right.

The United States leads in both production and production control of all five minerals. Great Britain is equal, or superior, to Germany in production of all except iron ore, in which she has only

half the output of Germany. France is plainly deficient in all five essential minerals. Therefore, Germany and Great Britain divide the control of production among the three European nations.

In the actual industrial control of raw materials, however, the matter is quite different. The United States still leads, as would be expected from her large production; Germany has plainly taken the foremost place in all except the lead industry. She controls by means of her imports as much fuel as Great Britain and about

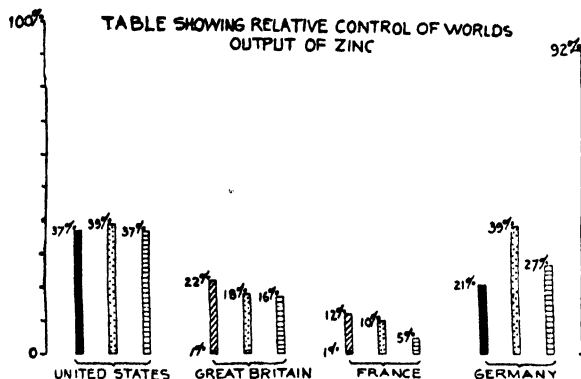


FIG. 4.

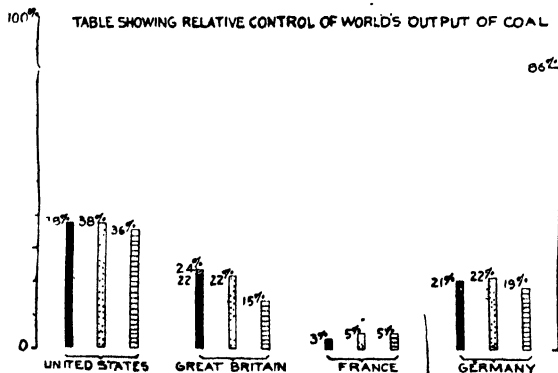


FIG. 5.

Figs. 4, 5.—Dominant control of the world's output of zinc and coal. Aggregate control shown by vertical line on right.

twice as much iron ore, copper, and zinc; France is far behind. The actual amount of fuel consumed for domestic and industrial purposes in Great Britain and Germany is nearly the same, but Germany's consumption control of crude copper, zinc, and iron is almost double that of Great Britain, while the industrial consumption of France again lags far behind.

An inspection of the scale on the right of the diagrams brings out the fact that these four countries control in their production

about nine-tenths of the world's coal and zinc; four-fifths of the world's iron ore; two-thirds of the copper; and over half the lead output of the world. A glance at the columns showing control of raw materials indicates that the world's industrial market of copper and zinc, and nine-tenths of the market of coal, copper, and lead, is in the hands of these countries. The balance of industrial power before the war lay between the United States and Germany.

Coal and iron.—In the case of France nature has dealt hardly with her in the matter of mineral resources and as long as she remains deficient in coal she will never become an industrial factor. Before the war the balance of fuel was too much upon the German side of the scale. Much of Europe's chance for a stable and enduring peace lies in an equitable redistribution of her coal and iron supplies. Various official suggestions from the governments of France and Great Britain appear to favor the restitution of the Lorraine basin to France, thereby transferring almost three-fourths of Germany's total of iron ore output. The necessary coke to handle this amount of ore is to be found partly by annexing the Saare district and partly by drawing on the high grade coal fields of Westphalia. In case the Rhenish Westphalian syndicate should refuse to export coal to Lorraine it is proposed that France should establish a reciprocity treaty with England whereby she can draw British coal in exchange for French iron ore. It is urged at the same time that iron ore exports to Germany should be restricted in order to prevent possibility of future war. These ideas meet with favor in various British journals.

Some German notions of a post-war distribution of coal and iron have come to us through French sources. It seems probable that they are a fair representation of prevalent opinion in the German commercial world. A memoir addressed to the Imperial Government in December, 1917, by the Association of German Iron and Steel Industries and by the Association of Metallurgists is in favor of peace without annexation except for the acquisition of Briey which they claim would assure to Germany in the next war considerable resources in domestic ore. The *Wirtschaftszeitung* of the Centralmächte calls attention to the fact that the annexation of Briey would cause unfortunate competition with the German blast furnaces already in operation. It might be better to allow France to retain possession of Briey and to send her ore to Germany. It appears that Germany has contemplated the possibility of exceeding the American iron and steel production by means of the resources of the Briey basin and by the further development of German interests in Normandy.

A clear exposition of the French attitude towards the coal and iron problem by L. DeLaunay¹ has unfortunately never been translated into English. The second part of the book deals with the treaty of peace and post-war conditions. He discusses the coal situation of Europe and calls attention to the fact that the production of Germany had increased nearly 20 per cent in the five pre-war years while the production of Great Britain had remained nearly stationary during the same time. He emphasizes the excellent quality of the coal of Westphalia, which amounts to two-thirds of the actual coal production of Germany (lignite excluded). He notes the low cost of extraction of coal in Germany due to the natural ease in working their coal deposits and to the installation of machine cutting in German mines. To this natural richness in coal he ascribes the longing of the Germans to possess not only the iron ore of German Lorraine but even the share that remained to France in the field of Briey and Longwy.

He then acknowledges the absolute deficiency of France in coal and calls attention to the fact that her reserves are far surpassed by those of England, Belgium, and Holland. He discounts as impractical the possibility of further important reserves being found beneath the Paris basin and he disposes of France's water power as an inadequate substitute in addition to the fact that the electrometallurgy of iron is not yet available for any but special purposes. He, therefore, states that France is dependent for necessary coal upon the approaching treaty. The production of Belgium is not sufficient to supply the deficit, and importation from England would not be profitable. He will not allow that France should be relegated, for lack of sufficient raw materials, to the position of a manufacturer of only highly refined and specialized finished products, justly contending that she has shown in the past war that she is far from being in the position of a dying nation that must be sustained by unnatural and selected industries. He claims on the contrary that she is entitled in return for her noble efforts to sustain herself against invasion to have a certain reparation for the injuries that have been dealt to her by nature in her scant endowment of mineral wealth.

He demands therefore the restitution to France of Alsace-Lorraine with her annual output of 21,000,000 metric tons of iron ore, together with the Saare basin and its annual output of 17,500,000 metric tons of coal and complete freedom to utilize the ore so acquired.

He then proceeds to examine what would be the situation if France in order to paralyze the iron and steel industries of Germany should refuse to export her iron ore to the Germans. The pre-war production of iron ore in French Lorraine was 19,500,000 metric tons, and her exports 8,000,000 tons. By adding to this the 21,000,000 tons of

¹ DeLaunay, L., "France-Allemagne," Librairie Armand Colin, Paris, 1917.

German Lorraine France would have at her disposal 40,500,000 tons of ore, as opposed to 11,500,000 which she smelted in 1913. For the additional ore almost 31,000,000 tons of coal would be required, if 5,000,000 tons of ore were exported to Belgium and Holland. The 1913 production of France in coal was 41,000,000 metric tons and her consumption, according to De Launay, was 62,000,000 tons, leaving a deficit of 21,000,000 tons. The requirements of the numerous blast furnaces already in operation in German Lorraine would bring this deficit up to 52,000,000 or 53,000,000 tons. The annexation of 17,500,000 tons of coal in the Saare basin would still leave about 36,000,000 to be supplied. Out of 21,000,000 tons imported in 1913, 10,000,000 came from Great Britain and 4,000,000 from Belgium, the remaining 7,000,000 chiefly from Germany.

De Launay contends that neither Great Britain nor Belgium could furnish much more than her pre-war quota because of the insufficient supply of Belgium and the difficulties attendant upon the long haul from England to the Lorraine furnaces. It would be necessary then to purchase about 22,000,000 tons of coal from Germany and he insists that the elimination of commercial relations with Germany is out of the question.

France is face to face with the problem of either exporting ore from inability to smelt or of buying coal and coke from Germany and maintaining her furnaces at the risk of overproduction or else of closing her mines. In other words, France would then be contending with the problem that beset Germany during the years of her phenomenal industrial rise, only with this difference, that whereas Germany had a great temptation to overproduction with her richness of combustibles, France has to go abroad to search for the means of maintaining her furnace output. De Launay does not take kindly to the idea of restricting mine output, for, although he acknowledges that there are advantages in holding reserves, he also maintains that the progress of metallurgy may, in a comparatively short time, displace these phosphorus ores of Lorraine for some other type such as siliceous or arsenical iron ore. He advocates the exportation of ore on a reciprocity basis to Great Britain. But he acknowledges that this would not dispose of the large stocks of iron ore that France would have to offer.

France must sell iron ore to Germany, provided that she receives in exchange for it the coal that she requires. This exchange should be made under favorable conditions such as those assured to Germany by the treaty of Frankfort in connection with the textile industries of Alsace. The peaceful interchange of commodities should not begin until after a period during which Germany should furnish France with coal without compensation and during which the exports of French iron ore should be completely closed to Germany in order

to paralyze certain German factories before they could revert from a war to a peace basis of production. He would, moreover, reserve to France the right to place at all times in the future such embargoes on exports to Germany as she might deem necessary in order to prevent the recurrence of war.

De Launay is not blind to the fact that the ultimate disposition of Alsace-Lorraine is complicated by the German nationality of one part of her people. Moreover, he appreciates the domination of German interests in the iron and salt syndicates, etc., and he realizes that even if it were possible to rid these institutions of their German domination they would still be controlled not by French but by various foreigners, Swiss, Swedes, and the naturalized American Jews of Frankfort. The suggested solution of this problem is the expropriation of the German inhabitants of Alsace-Lorraine. The industrial syndicates are to be combined into a syndicate of the *Gewerkschaft* or localized type, as opposed to the *Gesellschaft* or imperial type. That is to say, they are localized under one controlling power only exercised in Alsace-Lorraine. The directors and stockholders of these new companies are to be entirely French or members of allied nations. In order to enforce this the stock is to be all registered. He acknowledges that in spite of these safeguards it is likely the Germans will obtain a surreptitious hold upon the administration through factitious shareholders. It would not be likely, however, that Germans could continue to exercise such a complicated and costly method of supervision in Alsatian affairs. It is more probable that they would retire and construct new factories in the Ruhr district.

In conclusion De Launay insists that without coal France can not handle the increased iron and steel industries consequent upon the annexation of Alsace-Lorraine, that the necessary coal can not be obtained at sufficiently low price from Great Britain on account of transportation cost, that the factories of France could not work up the crude products of the Lorraine ores, and that the raw materials would necessarily continue to be exported to Germany. In case they are sent to Germany, subject to customs duties, the iron and steel of Lorraine would not compete with the products of the Luxemburg furnaces, which pay no duties. He, therefore, stipulates that the portion of the iron and steel output which was formerly absorbed by the German market should be admitted to Germany duty free. He also warns his readers that the German iron and steel industries will never be extinguished so long as they have access to the foreign ores of Sweden and so long as they exercise control over the Duchy of Luxemburg.

A note of warning is sounded by Dr. C. W. MacFarlane¹ in "The Economic Basis of an Enduring Peace" published in 1918. He goes further than De Launay and suggests the expropriation of the coal fields of Westphalia in order to secure to France the necessary fuel for her industries. He disposes of the problem of the assimilation of the German people of Westphalia by stating that France is more successful in dealing with her colonies than Germany and he claims that the German population would be contented to become citizens of an industrial republic rather than of an absolute monarchy. Whether these reasons would be sufficient to insure the successful assimilation into France of a population more essentially German than Alsace-Lorraine is French is a matter of some doubt, but he realizes that by depriving Germany of 75 per cent of her available supply of iron ore and by assigning to France 60 per cent of German coal in the district of Westphalia we would completely wreck Germany as an industrial power. He therefore proposes to turn over to Germany the control of Turkey in Asia, in order that she may rehabilitate her iron and steel industries with the high-grade magnetites of Asia Minor. This solution of the difficulty with its necessary concomitant of an all-rail route between Germany and Asia Minor, with a tunnel under the Bosphorus, and a proposed federated Balkan State under international guaranty, will not appeal to the many people who conceive that the increasing participation of Germany in near eastern affairs is already a distinct menace. And if it has proved impossible to assure the integrity of a nation like Belgium, which is a well established unity, we may be pardoned for declining to assume the responsibility of welding the seething Balkan turmoil into any sort of federated State under an international guaranty. Nevertheless, MacFarlane's book serves a needed purpose by pointing out what we are liable to forget in our natural desire to see the industries of France placed upon a stable basis—namely, that by depriving Germany of practically all her iron and by annexing to France so much of German coal that there shall be no commercial interdependence between France and Germany, we are transferring the predominance of industrial power from Germany to France. In fact, we would transfer it to such good effect that we would relegate Germany to a position of industrial impotence at the same time that we placed an undue industrial supremacy in the hands of France, who would then control by her production two and a half times as much iron ore as Great Britain, and almost six times as much as Germany. Such a situation would not be entirely free from danger to the future peace of Europe.

Tungsten.—Through French sources have come various interesting ideas for the post-war disposition of other minerals less important

¹ MacFarlane, C. W., "The Economic Basis of an Enduring Peace," Geo. W. Jacobs & Co., Philadelphia, 1918.

than iron and coal. It is unfortunate that we have received so far no information concerning their ideas on the subject of copper, lead, and zinc. Great hopes are entertained by the French Government for a post-war tungsten industry that would lie chiefly in the hands of the Allies. The position of the ferrotungsten industry before the war was one of the most striking examples of Germany's industrial domination of a raw material in which she is herself essentially lacking. In 1913 Germany produced only about 1 per cent of the world's output of tungsten ore reckoned in terms of 60 per cent tungstic acid. Yet through her imports she controlled over 60 per cent. of the world's output. Great Britain, including her possessions, produced 37 per cent of the world's output, yet she was dependent entirely upon Germany not only for ferrotungsten, but also for her tungsten steel tools, which even though purchased through English firms were derived from German manufacturers. France's production of 1913 amounted to 2 per cent of the world's output, and in addition to this she controlled the production of the French mine of Borralha in Portugal, and possessed an interest in the Bolivian enterprises. Owing to her development of water power she had a pre-war production of ferrotungsten, though it is certain that she was not at that time in a position to compete with the German market of ferro alloys, still less with their output of high-speed tools. Her comparative poverty in this respect is shown by the statement in *La Metallurgia* for April 30, 1918, that her consumption of ferrotungsten had increased from 250 to 1,800 tons as the result of the war. The suggestion is made that in the future tungsten ore should only be sold to Germany at very high price in order to maintain the high price of tools. On account of the difficulty of successfully concentrating the tungsten business on a financially profitable basis it is suggested that the tin and tungsten industries might be organized into a combination which would increase the power of the Allies in the Bolivian field, at the same time frustrating the activities of Germany in that respect.

The English ferro industry has reached such a point that after the war it will be able to handle all the British production of molybdenum, which is nearly one-third of the world's output. From French sources comes the suggestion that the four French ferro producers can, by reason of their cheap water power, handle all the tungsten or molybdenum which the British might find difficult to dispose of on account of the high cost of production in times of peace.

Vanadium and uranium.—Owing to the American control of the vanadium output, the American Metal Company will become the center for a combination which should dispose of the world's supply of vanadium in such a way as to eliminate Germany's participation in

the ferro-vanadium business and to relegate her manufactures requiring vanadium steel to an unimportant position. Since the United States is the principal producer of uranium ores it would seem possible to combine the management of the vanadium and uranium output so as to place the uranium business on a self-supporting basis, not dependent upon state assistance, which is an artificial way of sustaining an industry. On account of the possibility that German reserves of uranium may be increased by further exploitation the French writers urge upon the Allies the necessity for vigorously pursuing their efforts to keep the monopoly of these ores in their own hands.

Antimony.—Although it might seem at first sight that the control of the antimony market would lie in the hands of the Allies on account of the fact that most of China's production is treated in the smelters of England, France, and Belgium, yet the fact that in January, 1917, the Central Powers no longer showed evidences of the antimony shortage from which they suffered at the beginning of the war would indicate that they had succeeded in increasing their resources to a considerable extent, doubtless by exploitation of the Turkish deposits. It is, therefore, probable that after the war they would be self-sufficient for the small peace-time requirements of antimony.

Tin.—In regard to the tin industry, which has hitherto remained almost exclusively under the domination of the Metallgesellschaft and the Dutch market which handles one-sixth of the world's production, French writers indicate the necessity of organizing the interests of the Allies and of those neutrals who are outside of the sphere of German interests. The British Empire is the principal producer of tin and her enterprises are becoming gradually more coherent while she is ridding herself of the dominant Anglo-Holland interests. It is easy for her to increase her production, to extend her smelters in the British East Indies, and also to establish in Australia a hold which should stamp out growing German influence in that country. She would in time be able to dominate the mines of Siam by extension of her interest in the Malay Peninsula. Bolivian mines should be carefully protected from German influences. The French industry should be stimulated. Belgium might readily enter the field of the smelting, and the United States occupies a position of growing importance on account of her de-tinning industry. The Allies could easily recover from tinplate scrap in English, French, and Italian works enough to supply all their needs in tin chloride, and in addition have forty to fifty thousand tons of steel available for use by re-fusion.

Phosphates.—As far as phosphates are concerned the Allies have a virtual monopoly of the situation on account of the large produc-

tion of the United States and of the French possessions in northern Africa. The principal German sources of supply formerly lay in the Marshall Islands and in the phosphatic slags furnished by the basic iron industry of Lorraine. The latter source will be transferred to the French with the accession of Alsace-Lorraine and the output of the Marshall Islands is now controlled by an English company which finds its market chiefly in Japan and Australia. Germany might find a supply in the guanos of South America. The Peruvian deposits are however controlled by an English company and the guanos of Oceania are in the French or British islands, so that the only deposits available for Germany are those of the Patagonian coast of the Argentine Republic, whose output amounted to only 28,000 tons in 1913. Bone phosphate and phosphate extracted from animal refuse is a considerable industry in Germany and a prominent company for the production of chemical fertilizers in Paris was under German supervision, a fact that is noted by the French as requiring action on the part of the French Government. In general the phosphate apportionment is susceptible of easy regulation from the Allied point of view and it could well be fixed by an interallied committee for the apportioning of raw materials. Such a committee would watch not only over the exports from various producing countries but also over the imports into Germany. The danger of overproduction in France from her natural phosphates and from her increased output of basic slag would be small even if her production did not find a market in Germany. The agriculture of France after a long period of inaction and devastation will require an intensive fertilization similar to that of Belgium, which employs 380 kilograms of superphosphate per hectare of cultivated land, as against 83 kilograms per hectare employed by France before the war. The consumption of phosphatic fertilizer in France could readily be increased by a judicious propaganda launched by the producers. A reduction in the supply of phosphate to the Central Powers would greatly decrease the sugar beets in Germany, thereby reducing appreciably her export of sugar.

CONCLUSIONS.

The various suggestions proposed are interesting possibilities for the post-war regulation of mineral distribution. In the present emergency while France is exhausted by her long struggle, practically depleted of man power, devastated in her own industries and in those that are to be acquired in Alsace-Lorraine, some such appointment of output as that outlined above is not only advisable but absolutely essential.

We must now furnish the necessary handicap to German industry that will allow sufficient time for France to rise to the industrial

prominence made possible by her own acquisitions of iron and coal. Nevertheless, in dealing with a situation that is obviously abnormal it is not well to shut our eyes to the fact that a healthy and normal condition of international industry will always be governed to a large extent by the natural laws of supply and demand. To be stable the international balance of power must be in approximate equilibrium. Forewarned by the past, let us realize that in the industrial struggle which is a necessary part of the great struggle for existence no one can reach supremacy except by constant untiring effort. We must prevent Germany from becoming the dominant industrial market of the world, but the desired result should be attained not so much by choking German industry at its sources as by fostering and sustaining our own neglected industries until they reach a point where they can successfully compete with Germany in her own field. An outlaw nation in our midst will be a poor guarantee of future harmony. Let us stifle the military despotism of Germany, let us safeguard the revitalized industry of France, and let us quicken the erstwhile sluggish industries of Great Britain, then let us hope for a time when the great nations of the earth may indeed represent a true partnership banded together for common welfare. Wise men say that out of great wars come, along with destruction and devastation, great advantages to the human race. To-day while we yet stand only in the faint glimmerings of the dawn, it is hard to believe that out of evil comes good. Yet if the world shall have been able to realize, not only the cruelty and barbarism to which she refused to bow, but also the faults and short-sightedness by which many nations are in some sense responsible for allowing such a gigantic catastrophe to come to pass, and if each individual nation shall come to realize that she owes both to herself and to the world to fully develop her resources and her efficiency, not selfishly in order that she may swell her own power to the extermination of industrial development in other nations, but generously so that each nation may fulfil the share of human welfare imposed upon her by Nature, then and then only will the Great War bring forth lasting good to humanity.

REPTILE RECONSTRUCTIONS IN THE UNITED STATES NATIONAL MUSEUM.

By CHARLES W. GILMORE,

Associate Curator of Paleontology, United States National Museum.

[With 6 plates.]

A few million years before the Rocky Mountains were born and when that region was a land of lakes, rivers, and luxuriant vegetation, it was inhabited by a race of strange reptiles, upon whom science has bestowed the appropriate name dinosaurs or terrible lizards.

Some of these dinosaurs were the largest animals that ever walked the earth and some were very small. They differed greatly in size, shape, structure, and habits. Some were plant eaters; others fed on flesh. Some walked on four feet; others with small weak fore limbs walked upon the strongly developed hind legs. Some had reptile-like feet; others were bird-footed. Some had toes provided with long sharp claws; others had flattened hoof-like nails. There were dinosaurs with small heads and others with large heads. Some were large and cumbersome; others were small, light, and graceful and so much resembled birds in their structure that only the skilled anatomist is able to distinguish their fossil remains. Some of large size were clad in coats of bony armor, which gave them a most bizarre appearance.

The fossil remains of many of these various kinds of dinosaurs are now on public exhibition in the United States National Museum, and it is the purpose of the present article to describe some of the more interesting features of a few of these great brutes.

The first skeleton of a dinosaur to be displayed in the United States National Museum was that of *Trachodon annectens* (Marsh), popularly known as the Duck-billed dinosaur because of the general resemblance of the widely expanded nose to the bill of that bird. It was mounted in 1903.

It was one of two nearly complete specimens obtained many years ago (1891) on Lance Creek, Niobrara County, Wyoming. The completeness of the specimen is due to the fact that the animal after death was quickly covered with sand, and before decomposition had set in. The result being that the bones remained articulated,

the ribs attached to their respective vertebrae, and the great thigh bones remaining in their sockets, the legs being retained in a walking position as shown in the reproduction of the mounted skeleton.

Unfortunately the wearing away of the inclosing sandstone in which the skeleton was embedded had exposed some of the bones and portions of them had been damaged prior to its discovery. This refers especially to the front half of the skull, which had entirely weathered away. This has been restored from another more perfect skull, as have other minor parts of the skeleton which were missing. The skeleton is 26 feet 4 inches long; 11 feet 6 inches high from the base to the top of the head, and 8 feet 2 inches to the top of the hips. The skull is 3 feet 5 inches long; the thigh bone 3 feet 4 inches, while the track of this animal would have been about 21 inches in length and breadth. This is not the largest individual of its kind, there being several known skeletons that reach a length of 30 and more feet.

One of the most remarkable features of this great brute is the set of teeth with which the jaws were so well provided. In one respect these reptiles are much better off than the human being, in that as a tooth is worn out or lost it is replaced at once by another pushing up from beneath. Each jawbone has from 45 to 60 rows, and from 10 to 14 teeth in each vertical row, one above the other, the entire series moving slowly upward, and new germ teeth continually forming at the base to supply those worn away at the top. Thus it will be seen by a simple computation that there were over 2,000 separate teeth in the mouth of one individual.

The broad duck-like beak in life was probably covered with a horny sheath, as in birds and turtles of to-day, and admirably suited to the pulling up of rushes and other water plants, for this great creature was a herbivorous or plant-eating animal. That *Trachodon* was water-living is indicated by the webbed fingers of the fore feet and the long, deep latterly compressed tail, a most efficient swimming organ and equally useful as a counterbalance to the weight of the body when striding around on the hind legs on the land. Specimens have been found showing impressions of the skin covering, from which it has been learned that the animal was covered with a thin epidermis made up of tubercles of two sizes, the larger ones, as has been pointed out by Prof. Henry F. Osborn, predominating on surfaces exposed to the sun.

In the lower figure of plate 1 is a model restoration by the writer based so far as the proportions go on the mounted skeleton shown in the upper figure. The skin pattern is based with modifications on the published description of the wonderfully preserved mummified carcass of *Trachodon* in the American Museum of Natural His-

tory, New York, which has been so well described by Professor Osborn, and which has considerable portions of the skin areas preserved.

There lived at the same time with the *Trachodon* described above the horned dinosaur (*Triceratops*), the largest headed land animal the world has ever known. In plate 2 is shown a skeleton of one of these animals in the United States National Museum, mounted in 1904, and to this day the only skeleton of *Triceratops* in the world to be thus exhibited. It is known as a composite skeleton—that is, made up of the bones of more than one specimen, though the greater part of the skeleton pertains to one individual. These specimens were collected by the late J. B. Hatcher in the northern part of Niobrara County, Wyoming, a region from which he obtained the skulls and other skeletal parts of more than 40 individuals.

From the tip of the beak to the end of the tail, the *Triceratops* is 19 feet 8 inches in length, and in front of the hips is 8 feet 2 inches in height. The skull is 6 feet long, or nearly one-third the total length of the animal, and it is not an exceptionally large one, for skulls are known that measure 9 feet in length. Although the largest headed dinosaur, the brain of this creature is relatively smaller than in any known animal when the great size of the skull is taken into consideration.

That *Triceratops* was a fighter and often engaged in combat appears to be shown by the broken bones that are frequently found which have healed in life. A pair of horn cores in the National Museum bear mute witness to such an encounter. That one was broken off in life is evident from the fact that the stump had rounded over and healed, while the size of the remaining horn shows the animal to have reached a ripe old age.

The feeding habits of *Triceratops* were manifestly plant eating, as indicated by the tooth structure, the food probably being leaves and branches of low trees and shrubs. Hatcher¹ has pictured this country at the time these animals lived as being made up of vast swamps with wide watercourses that were constantly shifting their channels, the whole presenting an appearance similar to that which now exists in the interior of the Everglades of Florida. The entire region, where the waters were not too deep, was covered by an abundant vegetation and inhabited by these huge dinosaurs, as well as by the smaller crocodiles, alligators, turtles, and diminutive mammals, all of whose fossil remains are now found embedded in the deposits of that geological period.

The life appearance of *Triceratops* has been depicted by numerous paintings and several model restorations. In all of these the skin has been shown as smooth and leathery, but the discovery in recent

¹ The Ceratopsia, Monog. U. S. G. S., vol. 49, 1907, p. 194.

years of specimens having impressions of the skin preserved shows it to be made up of a series of nonimbricating scales.

The accompanying photographic reproduction (pl. 2, fig. 2) made of a recently prepared model restoration aims to embody all of the evidence of recent discoveries. Primarily it is based on the mounted skeleton shown in the figure above, and was made to a scale of one-fourteenth the linear dimensions of the original skeleton.

The nonimbricating, scale-like texture of the skin as represented in the model is based with modifications on skin impressions in the collections of the Geological Survey of Canada, at Ottawa; and although these impressions belong to one of the more primitive *Ceratopsians* it does not appear unreasonable to expect that all of the horned dinosaurs had a scaled integument, though the pattern of the scales probably varied considerably in the different genera. While future discovery will undoubtedly show the incorrectness of many features of this restoration, it at least graphically portrays some of the discoveries made during the past decade, and which have led to a much better understanding of the life appearance of these huge-headed, long extinct reptiles.

During the same geological period that the *Trachodon* and *Triceratops* lived there were many other and smaller kinds of dinosaurs. A skeleton of one of these, now in the National Museum, is shown in plate 3. This was collected in Wyoming in 1891, and it was in the nature of a surprise upon cleaning the rock from the bones in 1914 to find that it represented a dinosaur new to science. It was, therefore, found necessary to give it a name, and the name *Thescelosaurus neglectus* was coined for that purpose, the last or specific name being suggested by the seeming neglect on the part of those in charge of this beautiful specimen which had remained in the original packing boxes for 23 years after it was first discovered.

The value of a fossil is considerably enhanced when it happens to be one to which a new name is first given, for it ever after remains the standard for comparison by which others of its kind are identified. Such a specimen is called a type, and the greater the number of types in a collection of fossils, usually the greater its scientific importance.

The skeleton as here shown in the reproduction occupies relatively the same position as when found in the rock. The head and neck are missing, as are some few parts of other bones, as shown by the light-colored areas in the picture.

The importance of preserving articulated dinosaurian specimens in their original positions in the matrix can not be too highly estimated, particularly where they give positive information, as in the present instance, relating to the proper articulation and angulation of the feet and limbs. Unlike the mammals, the articular

surfaces in the dinosaurs are usually poorly defined, and afford little evidence concerning the exact manner of articulation of bones found detached and misplaced. For this reason any information conveyed by the finding of an articulated specimen with bones in sequential position in the rock is more to be relied upon than any number of expert opinions. As a rule specimens so exhibited also hold the attention of the average museum visitor far longer and arouse a keener interest in the genuineness of the specimens than does a skeleton that has been freed from the rock and mounted in an upright lifelike posture.

To the layman the type of *Thescelosaurus neglectus* is of interest as showing the skeleton in the same position as when covered up millions of years ago; and to the vertebrate paleontologists it will long remain a standard for interpreting and coordinating the scattered and isolated parts of others of its kind.

In life this animal was about 12 feet in length and evidently strong and agile in movement. The tail was long, equaling one-half the entire length of the skeleton, which served as a balancing organ when the upright bipedal posture was assumed. In rapid locomotion *Thescelosaurus* doubtless progressed entirely upon its hind legs, as do many of our living lizards, the short fore limbs being used for sustaining the fore part of the body when feeding from the ground.

While the head is unknown the resemblance of the skeleton to other well-known dinosaurs indicates that it was in all probability a plant eater. The foot structure would imply that it was more of an upland animal rather than an inhabitant of swampy areas.

In modeling the restoration shown in plate 3, the missing head and neck were restored from a closely related form in which these parts are known. In this model an attempt has been made to express the light, agile nature of *Thescelosaurus*, as is so clearly indicated by the skeleton and especially by the cursorial structure of the hind limbs.

The animals briefly reviewed in the preceding pages all lived during the Upper Cretaceous geological period, estimated by the best authorities as being between 6,000,000 and 7,000,000 years ago. Dinosaurs, however, existed long before that time in what is known as the Upper Jurassic, and attention is now called to typical representatives of the reptilian inhabitants of that period which is estimated to be 10,000,000 or more years old.

One of the most interesting was the *Stegosaurus*, or plated lizard. They were by reason of their large size and ornate bony skin structures the more striking and characteristic of the large reptilia that inhabited the Northern Hemisphere in those long past ages. It should be stated, however, that this family is not confined exclusively

to North America, for specimens have been found in England, France, and German East Africa that are but little unlike the American representatives.

Quite recently (1917) there has been placed on exhibition in the museum at Washington the skeleton of one of these curious beasts, shown here in plate 4, reproduced from a photograph. The skeleton as mounted measures 14 feet 9 inches in length, and stands about 8 feet high from the ground to the top of the highest plate. It was discovered in southeastern Wyoming—a region long famous for the many and well-preserved fossil specimens found there. Although collected more than 30 years ago it has only recently been exhibited to the public.

At present the origin of the family is not known, though it is now generally believed that they were descended from a bipedal ancestry, and that increasing bulk and development of the dermal armor caused them to lose celerity of movement, thus becoming sluggish, slow-moving creatures of low mentality. By measurement of the brain cavity in the skull of *Stegosaurus* it is found that the brain displaces but 56 cubic centimeters of water, with an estimated weight of about 2½ ounces. This small organ directed the movements of the creatures, estimated to weigh several tons, whereas the average normal human brain has a capacity of 900 cubic centimeters in a creature weighing from 130 to 150 pounds.

The most remarkable feature of the nervous system of this great brute, however, is the enormous enlargement of the spinal cord in the sacral region, which has a mass of more than 20 times that of the puny brain. At best the intelligence of this animal was of the lowest order, hardly more than sufficient to direct the mere mechanical functions of life. Whereas the great horned dinosaurs, with skulls from 3 to 9 feet long, were the largest headed land animals the world has ever known, the stegosaurus are the smallest headed when the great bulk of the body is taken into consideration. The jaws are provided with a dentition made up of teeth so small and weak as to be always a source of wonder and conjecture as to the real character of their feeding habits. It would at least appear to indicate that their food consisted of the most succulent of terrestrial plants.

The structure of the large broad feet suggest they were land haunting, doubtless of low swampy regions rather than the upland, and such an environment would be most suitable for furnishing the soft plant life necessary for their sustenance.

In addition to the small head and the great difference in the proportions of the fore and hind legs, the one most striking external feature of *Stegosaurus* is the unusual development of the skin armor, consisting, as it does, of two parallel rows of erect alternating bony

plates extending from back of the skull on either side of the mid-line of the back to the end of the tail, the tail being armed near the tip with two pairs of bony spikes or spines. There are also a considerable number of small rounded bony ossicles that in life were held in the skin and probably formed a mail-like protection to the head and neck. The primary purpose of this armor must have been for defense, protective to the extent of giving the animal a most formidable appearance rather than actually useful as a defensive instrument.

While the fossil remains of these animals are not uncommon in our museums, they consist for the most part of scattered and disarticulated bones. The one here figured is the only mounted skeleton of this animal in existence at the present time.

In plate 4, is shown a model restoration of *Stegosaurus* prepared by the writer and which portrays his conception of the life appearance of this animal. In this restoration is incorporated all of the latest evidence relating to its external appearance, and is thought to give a fairly accurate picture of the living animal. The recent discoveries of skin impressions with the fossil remains of other dinosaurian specimens makes it not unreasonable to expect that *Stegosaurus* had a scale-like integumentary covering, instead of the smooth elephant-like skin as here depicted. In the light of recent discoveries we may yet hope to have still more definite knowledge as to its true nature.

That the sluggishly moving *Stegosaurus* had need for his bony skin protection is indicated by the presence in the same geological formation of large flesh-eating dinosaurs. One of the most striking of these, though not the largest, is the *Ceratosaurus*, a carnivorous animal with a large head, having jaws filled with rows of strong, sharp-pointed teeth, that were well adapted to the seizing of its prey and the subsequent tearing and rending of the flesh. One of the distinctive features of this animal is the presence on the nose of a single, well-developed horn, and it was this horn that suggested to Professor Marsh the name *Ceratosaurus nasicornis*, meaning nose-horned saurian or lizard.

The exceedingly small fore limbs armed with sharp claws were not at all adapted to walking purposes, so that progression must have been entirely upon the strong hind legs.

This specimen was collected near Canon City, Colorado, during the years 1883 and 1884. The skeleton was found largely articulated in the rock, but many of the bones, especially the skull, have been greatly compressed and this flattening largely determined the selection of the bas-relief method of mounting it for exhibition, see plate 5. The backbone stands out in bold relief from the orig-

inal sandstone matrix, but the greater part of the background was made of a mixture of sand and cement, that when chiseled gives so close an imitation of the original sandstone as to make it difficult to distinguish one from the other.

The pose of the skeleton was determined by the position of the bones as originally found, and this remark applies especially to the left thigh bone, which was held by the rock in its proper position in the hip socket, which was directed backward at such an angle as to demand a walking stride. An attempt was therefore made to carry out the idea of a rapid walking motion and to make the other parts of the skeleton contribute to that effect. The long tail being raised clear of the ground acts as a counterpoise to balance the weight and compensate for the swaying of the body and forelegs.

The skeleton is 17 feet in length over all and about 5 feet high at the hips. There have been several life restorations made by various authorities; the latest done by the writer in 1915 showing his conception of the animal in the flesh is shown in plate 5.

In order to graphically present its flesh-eating habits the animal was modeled completing the killing of a small herbivorous contemporary, *Camptosaurus nanus*, an animal which could very well have been the prey of this rapacious brute. On the other hand some authorities are inclined to consider *Ceratosauros* to be a reptilian hyena that fed upon carrion; but, armed with teeth and claws such as they have, one can hardly believe they were intended entirely in the interests of peace.

We will now turn aside from the dinosaurs and in conclusion tell something about the *Dimetrodon*, one of the most striking and extraordinary forms of extinct reptilian life known from the North American Continent. In scientific circles this animal goes by the name of *Dimetrodon gigas*, but is popularly known as the Giant Spined Reptile, in reference to the high spines developed along the median line of the back, as shown in plate 6.

This specimen was found in northern Texas in the spring of 1917 by the veteran collector of fossils, Mr. Charles H. Sternberg, and acquired from him for the national collections. It is the most perfect skeleton of its kind known at this time and is the first one to be exhibited as a free mount, there being no less than three others elsewhere mounted in bas-relief. There were many difficult mechanical problems embodied in the mounting of a skeleton of such fragile proportions, but the success of the undertaking may be best judged by an examination of the photographic reproduction of the skeleton here shown. An idea of the painstaking care required in fitting together the broken pieces of bone, cleaning off the adhering rock, restoring missing parts, and articulating and mounting the bones may

be gleaned from the fact that 18 months of steady labor of one man was devoted to this specimen from the time it was received at the museum until ready for exhibition to the public. The pose adopted is one suggested by a careful study of living lizards, and is an attitude often assumed by those land forms of the present day when slightly irritated—that is, with the front of the body raised from the ground, the rear portion lowered with hind legs spread out, head raised, with jaws open, showing the rows of strong, slightly recurved teeth, as if angrily defying some one who had suddenly blocked his path.

Aside from the large head and strong short limbs, the most striking feature of *Dimetrodon* is the high dorsal fin along the back, formed by the lengthening of the neural spines of the vertebrae. These range in length from 6 inches on the neck to over $3\frac{1}{2}$ feet above the center of the back, where they reach their maximum development, becoming successively shorter as the tail is approached. That in life these tall spinous processes were united by a thin membrane of scaled skin there is little doubt. The foreign savants, Professors Abel and Jaekel, are disposed to think the spines were covered by skin, but not connected, but this seems highly improbable.

The one living lizard which appears to throw some light on the solution of this problem, and which is very remotely related to *Dimetrodon* is *Basiliscus plumifrons* from tropical America. The crest on the back shown in the inset in plate 6, though not so high or extensive as in *Dimetrodon*, is nevertheless supported by the elongated spinous processes of the vertebrae and these bear a striking resemblance to the crest of the extinct form. In general appearance all of the basilisks, of which there are several species, suggest the idea of lizards upon whose backs has been grafted a fish's fin, and it seems that in this animal we have the best suggestion of the probable appearance in life of the *Dimetrodon* fin or crest along the back.

In trying to account for some practical use for this unusual appendage it has been suggested that it may have resembled some of the ancient vegetation and thus served to conceal the animal as it lay in wait for its prey or for better concealment from its enemies. Professor Case, the acknowledged authority on the Permian reptiles, says of these:

The elongate spines were useless, so far as I can imagine, and I have been puzzling over them for several years. It is impossible to conceive of them as useful either for defense or concealment, or in any other way than as a great burden to the creatures that bore them. They must have been a nuisance in getting through the vegetation and a great drain upon the creature's vitality, both to develop them and to keep them in repair. The genus succeeded despite of them, or perished because of them.

That *Dimetrodon* was a carnivorous animal is clearly indicated by the powerful incisor and maxillary teeth which are admirably adapted for seizing and holding an active struggling prey. It is not probable that with his short bowed legs and heavy body he was ever capable of running fast or for long distances, but was certainly able to move swiftly for a short space, and thus from where he lay hidden in the vegetation made short, scuttling rushes upon his prey, ending possibly with a short pounce which permitted his weight to add something to the vigor of the attack by tooth and claw.

The edges of pools were probably the regions most densely populated by the varied amphibian and reptilian forms of the Permian period, and no doubt such places were favorite haunts of the *Dimetrodon*.

The National Museum skeleton has a length of about 7 feet, and from the base to the top of the highest spine measures 5 feet 6 inches, and while this is the largest species of its kind single individuals probably reached greater dimensions.

In plate 6 is shown a photograph of the restoration of *Dimetrodon gigas* based on the mounted skeleton and which shows the latest conception of the probable life appearance of this creature.

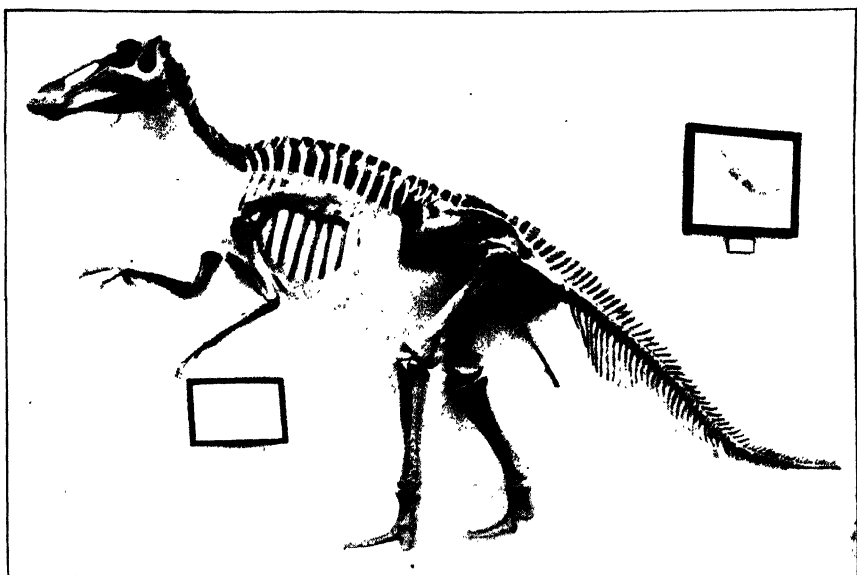


FIG. 1.—MOUNTED SKELETON OF TRACHODON ANNECTENS (MARSH).



FIG. 2.—RESTORATION OF TRACHODON ANNECTENS (MARSH).

Modeled by Charles W. Gilmore, 1915.

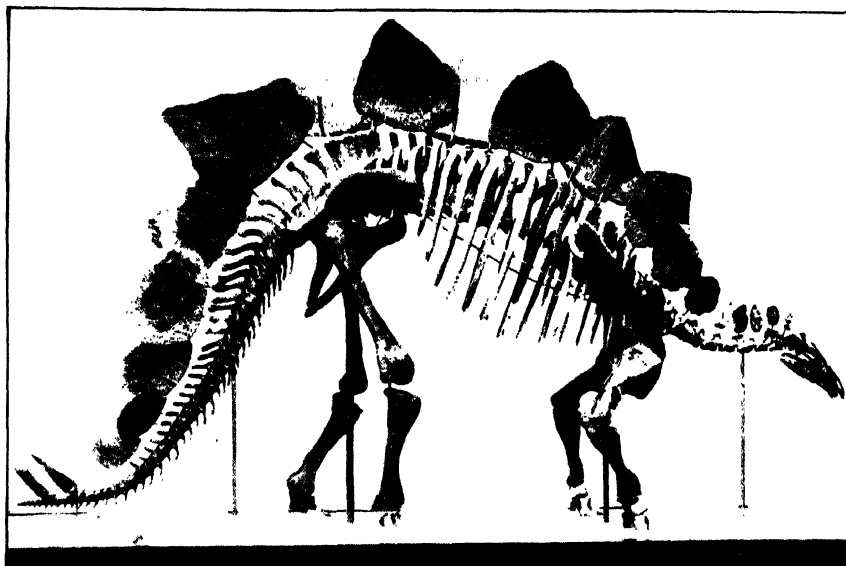


FIG. 1.—MOUNTED SKELETON OF STEGOSAURUS STENOPS MARSH.



FIG. 2.—RESTORATION OF STEGOSAURUS STENOPS MARSH.

Modeled by Charles W. Gilmore, 1915.



FIG. 1.—MOUNTED SKELETON OF CERATOSAURUS NASICORNIS MARSH.

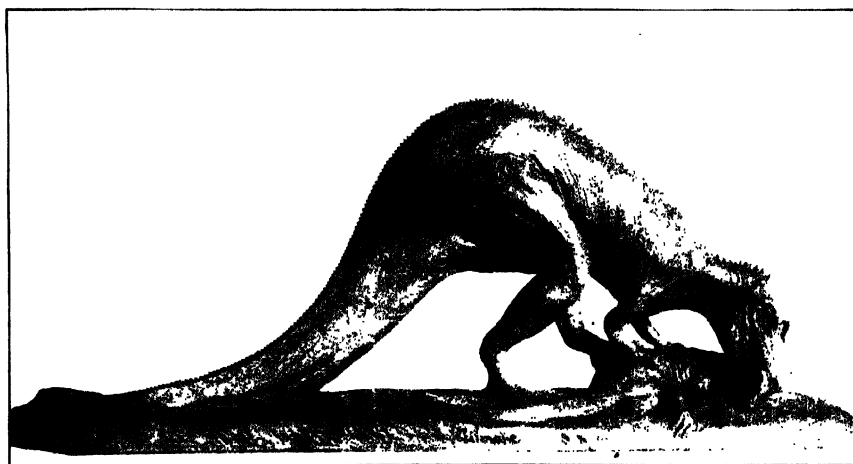


FIG. 2.—RESTORATION OF CERATOSAURUS NASICORNIS MARSH.

Modeled by Charles W. Gilmore, 1915.

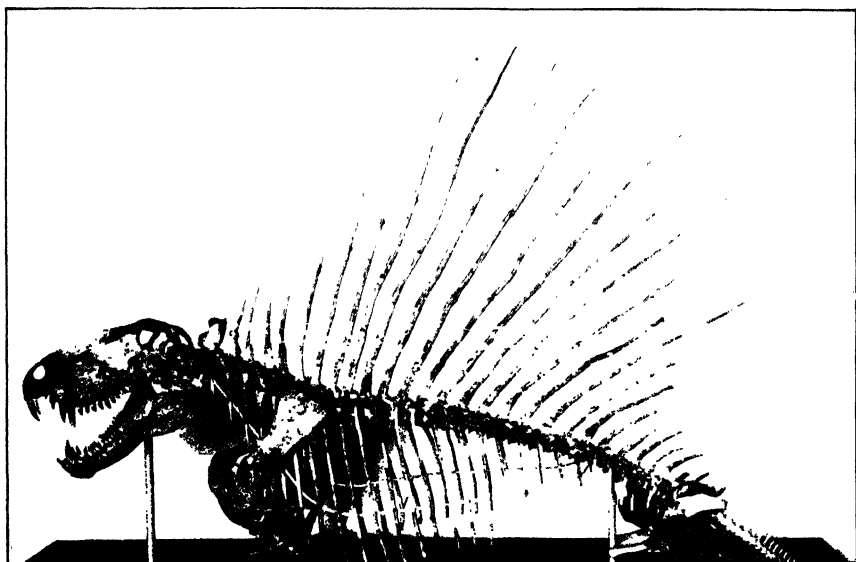


FIG. 1.—MOUNTED SKELETON OF DIMETRODON GIGAS COPE.

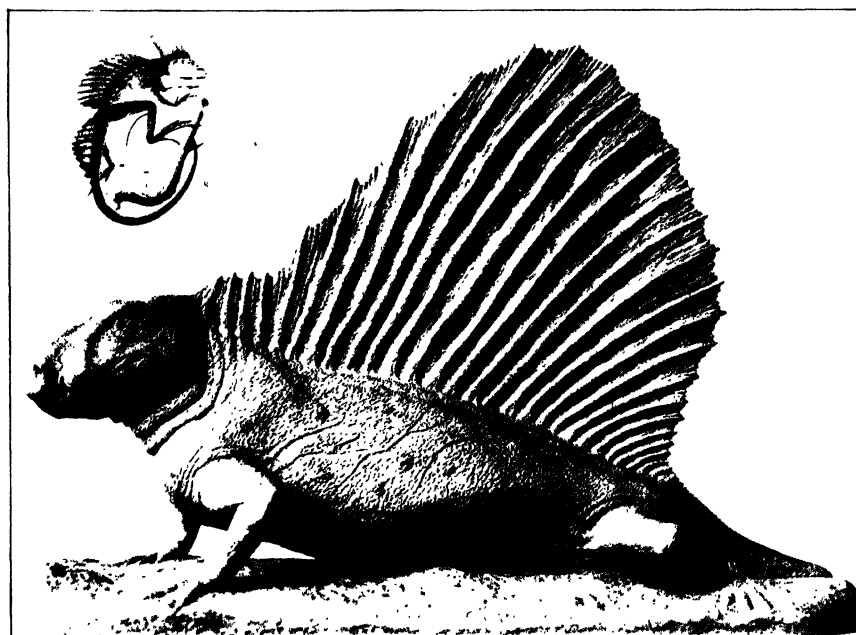


FIG. 2.—RESTORATION OF DIMETRODON GIGAS COPE. INSET: BASILISCUS PLUMIFRONS, A LIVING LIZARD.

Modeled by Charles W. Gilmore, 1918.

A PLEISTOCENE CAVE DEPOSIT OF WESTERN MARYLAND.

By J. W. GIDLEY,

Assistant Curator of Fossil Mammals, United States National Museum.

[With 6 plates.]

Caves are known in almost all portions of the globe. They usually occur in the softer rock formations of the nature of gypsum, sandstone, and particularly limestone. The peculiar nature of limestone, which is usually hard enough to be very resistant, but is slowly soluble in the presence of certain acids taken from the air by falling rain, make it especially susceptible to the development of underground caverns. These sometimes attain enormous size and usually follow the general lines of stratification or some fault or fissure where surface waters may find more ready access. Thus in limestone regions caverns, or caves both small and large, are likely to abound, and in certain localities occur in great numbers. Cave deposits containing bones of extinct animals, however, are comparatively rare in America, and their discovery, through the very nature of their occurrence, is usually purely accidental. It was through one of these accidents that such a cave deposit was discovered a few years ago in the vicinity of Cumberland, Maryland.

In the spring of 1912 there was brought to the United States National Museum, for inspection and determination, a portion of a lower jaw recognized as belonging to an extinct and hitherto unknown species of the wolf kind, together with a few other fossil bones which had been picked up from the bottom of a newly excavated railroad cut about 4 miles northwest of the city of Cumberland, Maryland. These specimens had been sent in and were afterwards presented by Mr. Raymond Armbruster, a local amateur collector of Cumberland, and his uncle Mr. George Roeder, of Swetnan, Virginia. The fossils at once aroused interest, and on invitation of these gentlemen, who reported good prospects of obtaining more such specimens from this recent excavation, a personal inspection was made. The cut is situated on the south side of Wills Creek Valley, where the tracks of the Western Maryland Railway pass westward through a low limestone ridge, or spur, to enter Cash Valley. The material from which the fossil bones had been taken

was found to be a true cave deposit, presenting a small exposure, or outcrop, at the base of the almost perpendicular southern wall of the cut which at this point is about 100 feet deep.¹

This preliminary examination revealed the fact that, while great quantities of the bone-bearing material had been blasted out and carried away by the steam shovel, there still remained a considerable mass which had not been disturbed and which promised to be well worth a thorough exploration. Following the report of conditions and prospects to the museum authorities, a systematic excavation for the careful collecting of the fossil bones was undertaken. The deposit proved to be of considerable depth and extent, and very rich both in quantity and quality of fossils, which were exceedingly varied in kinds of animals represented.

The work, begun in the spring of 1912, proceeded at intervals as the limited available funds permitted, and was not completed until the spring of 1915. A preliminary report of the results of the first two expeditions was published in August, 1913.² At this time there had been recognized in the collection, 29 species distributed among 6 orders of mammals. The work of the following two years yielded many more specimens, and among them were the best obtained at this locality. Incidentally these also added many new species to the list reported in 1913, so that the list now includes no less than 45 distinct species or kinds of mammals referable to seven different orders. To these may be added a few species of reptiles, including two snakes, and a species of alligator or crocodile. The actual identity of the latter is not certain, since it is represented by only a single tooth.

The mammals represented constitute a varied and, in some respects, strange assemblage. They range in size from a bat smaller than a house mouse to a mastodon which attained the size of an elephant. Probably none of these except the bats could properly be called cave living animals. Most of the species are now extinct, although many of the extinct forms belong to present day genera,³ and doubtless very closely resembled their living relatives. Among those animals referable to living genera are bats, shrews, squirrels, porcupines, ground hogs or woodchucks, field or pocket mice, wood rats, beavers, rabbits and picas, bears, wolves, lynx, wolverines, badgers,

¹ The accompanying figure, pl. 2, presents a view of the location and immediate surroundings of this cave deposit as it appeared after a great part of the subsequent excavating had been completed. It will be noted that here the rock ledges or strata have been tilted up by mountain folding to a degree at which they are standing almost directly on edge. A faint trace of peculiar weathering leading almost directly upward to the summit of the cliff evidently indicates the original opening of the cavern to the surface of the ground before the railroad cut was made.

² Gidley: Proc. U.S.N.M., vol. 46 (1914), No. 2014, 1913, pp. 93-102.

³ A genus is a natural group or assemblage of species having certain distinguishing characters in common. For example the genus *Canis* includes all the species or kinds of true wolves and dogs.

minks, martens, horse, tapir, deer, and possibly a large species of antelope, big as an ox, which seems to be closely related to the eland now living in Africa. The exact relations of this antelope, however, can not at present be stated with certainty, owing to the fact that two jaws, carrying the cheek-teeth and a few scattered teeth and foot bones constitute all the remains now known of it. These differ but slightly in character from the corresponding parts of the eland, with which they were compared and this is why it was provisionally referred to the African genus. A more complete knowledge of the American animal may show that it belonged to an unknown group which is now extinct. Other extinct forms belonging to two or possibly three genera are related but are not ancestral to the living peccaries. The peccaries of the present day are considerably smaller in size and are confined in their habitat to tropical and subtropical America.

Many of the species in the collection are represented by bones of numerous individuals. Some of these are recognized by only a few jaw fragments containing teeth; others by numerous bones, including more or less complete skulls, jaws and other parts of the skeleton; while in all the assemblage only a single animal, and that belonging to one of the extinct species of peccaries, is represented by a nearly complete skeleton (see pl. 6).

Most of the big bones and skulls of the larger animals were found broken, and with few exceptions all bones were scattered and indiscriminately mixed throughout the mass of clay and cave breccia. This condition of deposition may be readily understood, when the character of the cavern as it formerly existed is studied. As already stated the fossil-filled chamber, before the railroad cut exposing it to view was made, reposed at a depth of at least ¹ 100 feet beneath the surface of the ground, with which it was connected by a small and more or less irregular opening leading almost directly upward, as indicated in the illustration, plate 2. This opening at the surface probably broadened out to form one of those depressions, or "sink holes," so frequently found in limestone regions, and doubtless acted as a natural trap for animals roaming in its vicinity, the cavern far below being the receptacle for their bones when the skeletons had become sufficiently macerated to fall apart and continue their downward journey through the small, irregular chimney-like opening. In this descent of a 100 feet or more it is quite evident how these bones became so broken and separated. The accumulation was probably gradual, extending possibly over hundreds of years, and this time element, in part at least, would account for the indiscriminate mixing of the bones of so great a variety of

¹ Erosion has doubtless carried away many feet of material from the summit of the ridge since these animal remains became thus entombed.

totally unrelated animals, most of which would not be found directly associated in life.

A critical study of these fossil bones, thus accidentally brought together and again accidentally discovered by man, unfolds a most interesting story of the mammalian life as it existed in the environs of western Maryland during some portion of the so-called "Glacial Period," or "Ice Age." It can not be assumed, however, that these 45 or more species included in the Cumberland Cave collection represent by any means all the different kinds of animals that lived in the locality at that particular period; for, it must be remembered, accident, as just stated, was the chief factor in the accumulation of this deposit, and doubtless many forms then inhabiting the region entirely escaped this pitfall and therefore left no record. Nevertheless, could one, looking backward some 50,000 or 100,000 years to that time, see only those forms represented in this collection as they appeared in life, a remarkable assemblage of creatures would be presented; more remarkable, in fact, than a glance at the list enumerated might at first indicate. One would at once recognize among these animals of the Pleistocene times, as already intimated, certain species very like some of those either living in the vicinity to-day or which have lived there within the history of civilized man. Then many others would be seen to resemble living forms now only inhabiting very far-distant localities; while still others would appear differing from any animal living anywhere in the world to-day.

Among those resembling living or recently extinct species of the neighborhood would be included two or three forms of bats, a small shrew, a wood rat, two or three species of pocket mice, a woodchuck, a "yellow" porcupine, a rabbit, possibly a wolf or two, a black bear, and probably a deer of the Virginia or white-tail variety. Most conspicuous and probably the most interesting feature of this ancient fauna is the large number of species which resembled present-day forms that are now known to inhabit only remote and, in some instances, very far separated localities. Among these may be especially noted the little coney rabbit, or picas, now confined in North America to the highest peaks of the Rocky Mountains; the Canadian porcupine, restricted in range to the western United States and Canada; the wolverine, a strictly boreal or northern animal abundant in the Arctic regions and not known to range farther south than northern Massachusetts, New York, and Michigan; a bear of the grizzly group, not known in recent times to have extended its range east of the Great Plains States; a tapir, now confined to tropical zones; a horse, its kind in nature now confined entirely to the Old World; a certain species of bat now living in northern Mexico; and two or three species of wolves now living in the western and northern regions of North America, and in Siberia.

In contemplating this list one must bear in mind that the fossil and living forms compared, with few exceptions at least, are not identical species, but these fossil forms doubtless in life would have closely resembled their present-day relatives in general appearance and probably in habits.

The especially interesting phase of this fauna of the Cumberland Cave deposit, then, is the association of remains of animals whose modern relatives are now living under widely varying climatic conditions, as well as distant geographic ranges. And in referring to the lists enumerated above one might well ask what sort of climate prevailed in the western Maryland region during that portion of the Pleistocene in which this deposit of bones was being formed?

Crocodiles or alligators are not known to have ever existed outside of tropical or subtropical climates, and, moreover, cold-blooded saurians could not have inhabited a locality where the temperature was accustomed to fall much below the freezing point. The present day tapirs and peccaries also are confined to tropical and subtropical localities. The presence of these creatures then, and especially the crocodile, seem strongly to indicate a warm climate for our cave-deposit fauna. On the other hand, the wolverine is always considered a boreal animal, normally associated with cold climate conditions and martens and minks, too, for the most part, now inhabit northern or at least temperate zones, while the little picas or coney rabbits, to-day are found living only in the higher altitudes of the Rocky Mountains or some of the colder regions of Asia and eastern Europe. The presence, therefore, of these animals may be taken as almost equally strong evidence of cold climatic conditions.

How, then, may one account for this intermingling of animals of such widely varying climatic zones? There are at least three possible explanations. The first, and most unlikely perhaps, would be to suppose that the animals of the Pleistocene sufficiently differed in habits from their living relatives as to render comparisons entirely untrustworthy; or, second, that the accumulated fossil bones of this deposit represent a lapse of time sufficient for a gradual local change in climate, from mild subtropic to boreal or arctic, conditions (or vice versa), accompanied by a gradual and appropriate change of faunas; or third, and to me the most likely supposition is that the average temperature of the general region, at least of the lowlands and valleys, was warmer then than now, while the mountain ranges and peaks in the vicinity, being less worn down by erosion were probably much higher and therefore colder, possibly even snow capped.

Such a condition would naturally bring the boreal faunas much farther south than we now find them, while the valleys and lowlands

might at the same time be inhabited with a distinctly southern fauna. A contributory cause for a more southern range of boreal forms may be found also in the probable fact that the southern extremities of the great pleistocene ice sheet were at the time not far distant from this particular region. Under these conditions, had they prevailed, a mixture of fossil remains of boreal and subtropic animals such as is indicated in the Cumberland cave deposit is very readily understood and may thus be satisfactorily explained. It might well be that animals of widely varied life habits could inhabit contemporaneously the same general region—the austral species occupying normally the lower, warmer levels, the boreal forms the colder regions of the uplands and mountain tops—while certain animals of each extreme might readily, during the course of seasonal changes, occupy alternately and temporarily an intermediate locality. Moreover, the very nature and occurrence of the fossil remains found in the cave mass suggests just such a possibility, while there was no evidence whatever of a gradual succession or displacement of faunas affecting the entire region which might have taken place during the period of the cave-deposit accumulation.

Nearly coincident with the Cumberland cave discovery, and quite as accidentally, a similar deposit was reported to the National Museum from a locality in West Virginia. This find did not prove nearly so rich as the former one, either in numbers of bones or kinds of animals represented, but is nevertheless of interest since it differs in some important respects from that of the Cumberland locality, while the fossils it contained show it to be about equivalent in age. The deposit was encountered in the course of developing a quarry in the limestone ledge situated on the west side of the beautiful valley of the Green Brier, near the little town of Renick.

Here the rock strata are nearly in their original horizontal position (see pl. 4) and the small cavern following the general line of stratification extended backward some distance into the side of the ledge with its original opening on the same level with the floor of the cavern instead of directly above, as at the Cumberland locality. This difference in physical structure is reflected, first, in the character of the deposit covering the floor of the cavern, it being a soft, loose cave-clay unmixed with broken stones; and, second, in the much fewer numbers, and less variety of bones found there. The few bones recovered for the National Museum, which include only one well-preserved skull, represent but a single species, and that species, strangely enough, closely related to or possibly identical with one of the large extinct peccaries of the Cumberland cave. Unfortunately, as in the case of the Cumberland find, the greater part of the bone-bearing material had been removed before any steps were taken to preserve the specimens it contained. It, therefore, is quite prob-

able that bones of other animals had also found their way into this deposit, but hardly possible that there was anything like such a varied assemblage of animal remains as was formed at the Cumberland cave; for here there was no natural trap or pitfall to assist in their accumulation, and the bones of the Green Brier deposit seem to have been dragged there by some large carnivorous animal, which in Pleistocene times may have used the small cavern as a den; or possibly these large peccaries may themselves have occasionally sought its entrance for protection or shelter.

Among other notable discoveries in the United States of cave formations containing fossil bones are the Port Kennedy cave deposits of eastern Pennsylvania¹; the Potter Creek Cave, of Shasta County, California²; and the "Conrad Fissure" bone deposit of northern Arkansas.³ Descriptions of these may be found by referring to the publications here cited.

In the Old World, and especially in Europe, discoveries of cave deposits containing bones of extinct species of animals have been more frequent than in America. This is probably due, in part at least, to the fact that much of the Old World is more densely populated and has been occupied by civilized man for a much greater period of time. Boyd Dawkins, a noted English scientist and writer has given a good account of these caverns in his interesting book on Cave Hunting, published by MacMillan & Co., London, in 1874.

An especially interesting feature of the European caves is the unmistakable evidence that many of them were inhabited for long periods, especially during the Pleistocene age, by large carnivores, such as hyenas and bears, and these animals were doubtless responsible for the accumulation of bone deposits found there representing many other animals which they had dragged into their dens for food. Many of the caves also show evidences of having been inhabited by early man. A good account of these evidences has been given by Prof. Henry Fairfield Osborn in his book on Men of the Old Stone Age.⁴

¹ Cope and Mercer, *Jour. Acad. Nat. Sci., Phila.*, (2) vol. 11, 1887 to 1891, pp. 193-289.

² Sinclair, *Univ. Calif. Pubs.* vol. 2, No. 1, 1904, pp. 1-27.

³ Brown, *Mem. Amer. Mus. Nat. Hist.*, vol. 9, pt. 4, 1908.

⁴ Osborn: *Men of the Old Stone Age*. Charles Scribner's Sons, New York, 1915.



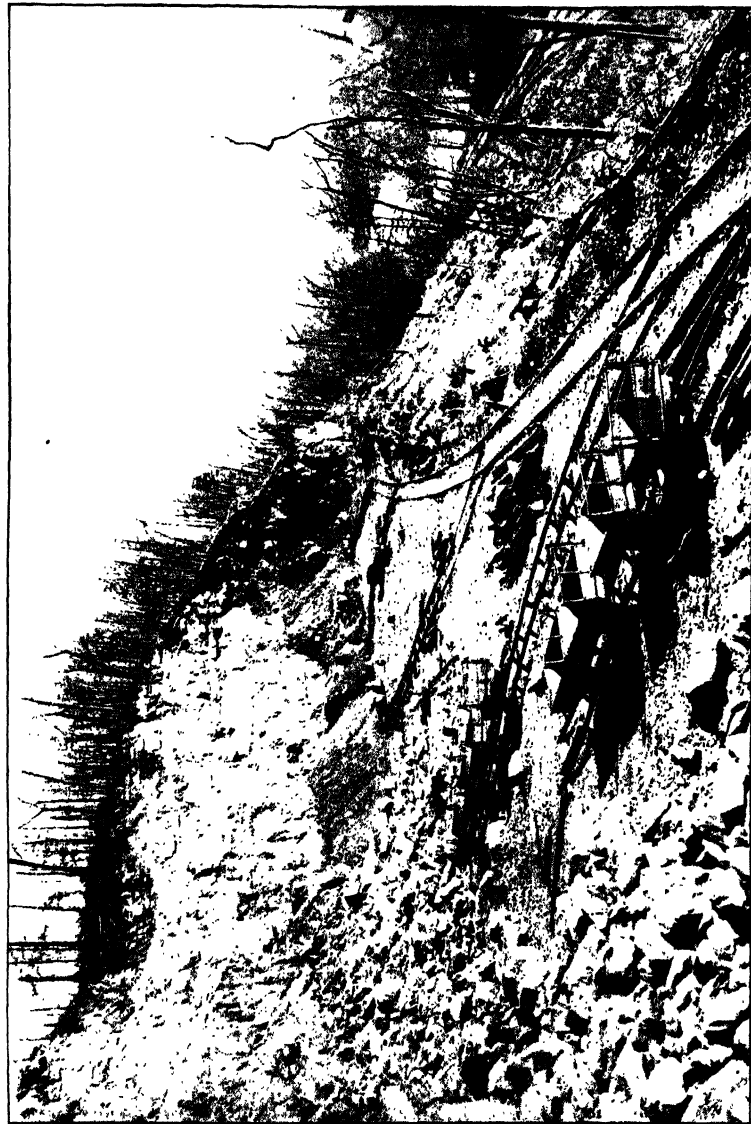
RAILROAD CUT WHICH UNCOVERED THE CUMBERLAND CAVE DEPOSITS.



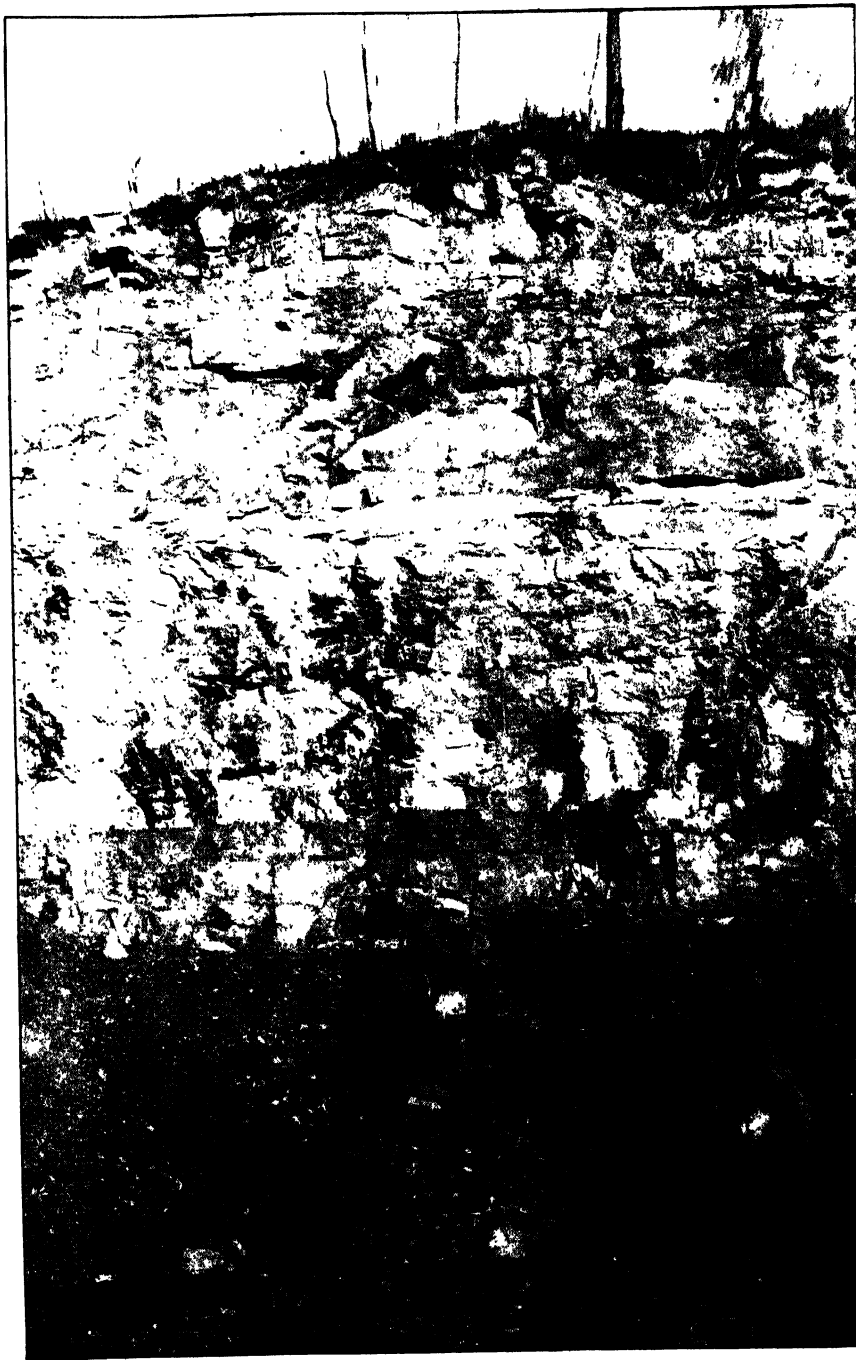
CAVE FORMATION IN UPTILTED LIMESTONE LEDGE.



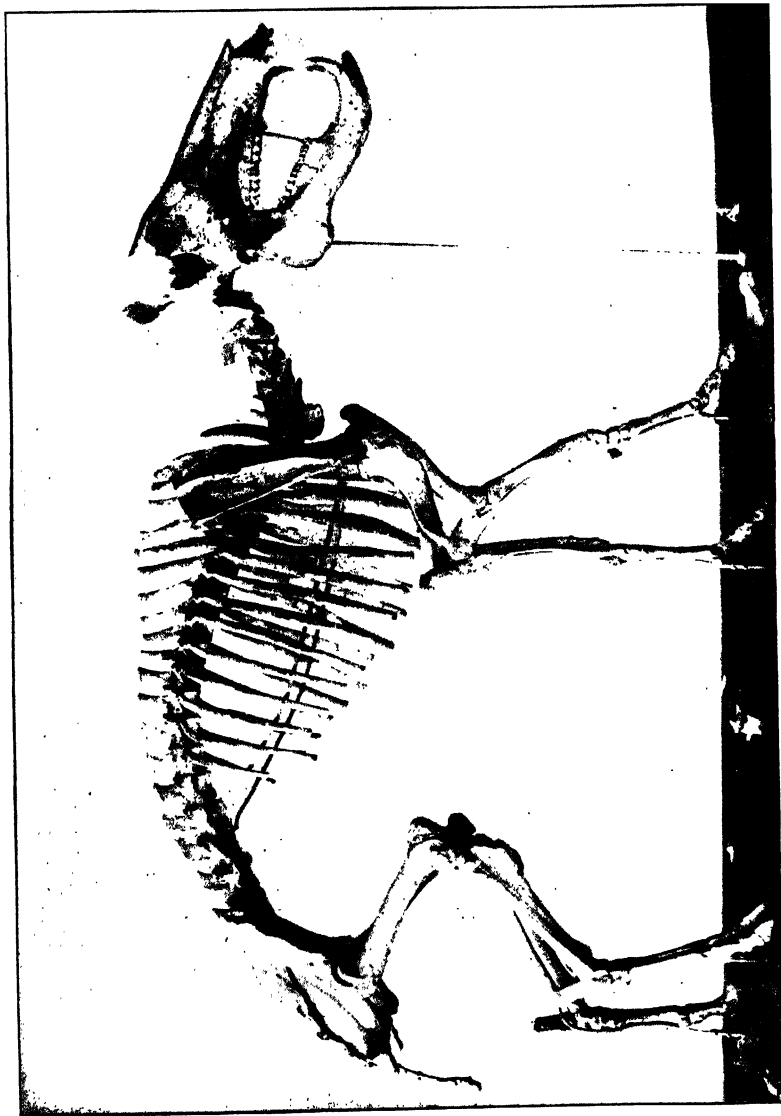
EXCAVATED CHAMBER FROM WHICH FOSSIL BONES WERE TAKEN.



STONE QUARRY NEAR RENICK, W. VA.



SMALL CAVE DEPOSIT IN STONE QUARRY NEAR RENICK, W. VA.



SKELETON OF *PLATYGONUS CUMBERLANDENSIS* GIDLEY FROM CUMBERLAND CAVE.

PALEOBOTANY: A SKETCH OF THE ORIGIN AND EVOLUTION OF FLORAS.

By Prof. EDWARD W. BERRY,
The Johns Hopkins University.

[With 6 plates.]

CONTENTS.

	Page.
Introduction	289
Methods of preservation	292
General principles	294
Relation to other sciences	297
Types of vegetation:	
Thallophyta	298
Bryophyta	300
Pteridophyta	301
Arthrophyta	311
Lepidophyta	322
Pteridospermophyta	334
Cycadophyta	340
Coniferophyta	352
Angiospermophyta	367
The evolution of floras:	
Stages of evolution	372
Pre-Devonian plants	377
Devonian floras	378
Carboniferous and Permian Cosmopolitan floras	381
The Glossopteris-Gangamopteris flora	383
Triassic floras	386
Jurassic floras	392
Lower Cretaceous floras	394
Upper Cretaceous floras	398
Tertiary floras	401
Pleistocene floras	406

INTRODUCTION.

The study of the former plant life of the globe possesses a many-sided fascination, not the least of which is the light which it sheds upon physical history. The term paleobotany, applied to the science of fossil plants, has come to be widely adopted of late years. Its story is not merely the history of the endless succession of plants which have inhabited the earth since life first came into existence, but it aims to understand and interpret these in terms of the evolu-

tion of individuals and of floras, their interactions with an ever-changing environment, and the transmutation of these facts into terms of ancient geography, topography, rainfall, temperature, and distribution.

The scientific study of fossil plants is a very modern development, for, notwithstanding the great abundance of fossil plants in the countries of the classical world surrounding the Mediterranean, the limestone quarries of the Greeks, the petrified forests of Nubia, and the vast public works of Imperial Rome, none of the writers of antiquity mention fossil plants, although some of them carried on a lively discussion regarding the nature of animal fossils. Petrified wood is not recorded until about the middle of the thirteenth century (Albertus Magnus), and fossil foliage not before the latter half of the seventeenth century (Major, Ihwyd). The earlier commentators explained fossils as due to the mystical action of the stars or the mysterious working of spiritual forces like the *vis lapidifica* of Avicennia, or the *virtus formativa* of Albertus Magnus, or the stone-making spirit of Sperling. Nothing was further from the accepted thought than that fossils were the remains of real organisms that had once lived; the nearest approach to such a view was that they were some of the models used by the Creator or that they had developed from abortive germs of animals and plants that had become lost in the earth.

After the view that fossils were the remains of organisms had gained many adherents, they were regarded as evidence of the universal deluge—an interpretation suggested by Martin Luther in 1539. This flood theory or diluvial hypothesis found numerous advocates throughout the seventeenth and even far into the eighteenth century. For example, in the Transactions of the Royal Society for 1757, James Parsons figures numerous fossil fruits from the early Eocene deposit of Sheppey in the Thames estuary. These, he thought, would furnish evidence of the season of the year in which Noah and the rest of creation were obliged to take refuge in the ark, and he concludes from the maturity of these fossil fruits that the deluge commenced in the fall of the year and not in the spring, as his contemporary, Doctor Woodward, had supposed. Johann Jacob Scheuchzer (1671-1733) was the great exponent of the flood theory, publishing his *Herbarium Diluvianum* at Zurich in 1709, and even figuring the bones of one of Noah's less fortunate brethren which he found among the fossil leaves at Oeningen on the Swiss border of Baden, and which subsequently proved to be the bones of a large Miocene amphibian.

The flood theory passed through various phases of opinion. At first the fossil plants were regarded as similar to those still growing in the vicinity—a natural enough belief when the universal accept-

ance of the Mosaic cosmology and a world but 6,000 years old is borne in mind. Subsequently, when the differences in the fossils became apparent, they were thought to represent forms still existing in the Tropics that had been swept to Europe and buried by the waters of the flood. When with the progress of knowledge of tropical plants this last view became untenable, it was thought that the fossils represented plants that had been exterminated by the flood, and from this it was but a slight step to the opinion advocated by Volkmann, which appealed to many, that the antediluvian vegetation was of a far higher order than that of the present with none of the thistles or other weeds of modern times, and that our modern forest trees are the degenerate descendants of delightful Adamitic fruit trees—a phytological fall paralleling and ascribed to the fall of man.

Gradually it came to be recognized that fossil plants were not only unlike recent ones, but that they were very ancient and not merely antediluvian but pre-Adamitic—a view first advocated by Blumenbach (1790). The first year of the nineteenth century saw the publication of the *Beiträge zur Flora der Vorwelt* by Ernst Friedrich von Schlotheim (1764–1832), in which 14 plates of fossil plants were published, and these plants were segregated into 5 classes and 12 orders which were based upon the method of preservation. The next work of importance, with a somewhat different point of view as its title indicates, was the *Versuch einer geognostisch-botanischen Darstellung der Flora der Vorwelt*, published in parts from 1820–1838 by Kaspar Maria von Sternberg (1761–1838). The vegetation of the world was divided into three periods—an older insular period characterized by the coal plants; a period marked by cycadean types, which corresponds roughly with the modern Mesozoic; and a period introduced by fucoidal remains and characterized by dicotyledonous leaves, which corresponds with the modern Cenozoic.

The real Nestor of paleobotany, however, was Adolphe Theodore Brongniart (1801–1876), the son of Alexandre, who was associated with Cuvier in his great work on the Paris Basin. Brongniart commenced publishing on fossil plants at the early age of 21, and in 1828, in his *Prodrome to the Histoire des végétaux fossiles*, he drops the prevailing point of view and treats fossil plants as none the less plants, endeavoring to fit them into the natural system of classification of Jussieu, and recognizing the true position of the gymnosperms a generation or more before the students of the modern conifers arrived at the same point of view. Brongniart maintained that there had been a steady progress from lower to higher forms. He believed in a gradually ameliorating climate, and divided the extinct vegetation into four periods, the first extending from the beginning to the end of the Carboniferous, the second corresponding to the early Triassic (grés bigarre), the third including the later Triassic, the Juras-

sic and Cretaceous, and the fourth making up the Tertiary and Quaternary or Cenozoic. He thus laid the foundations of the science in a broad way and was the inspiration of numerous students who grew to productivity under his tutelage and example.

During the remainder of the nineteenth century a vast body of literature was built up by an ever-increasing number of students, of whom the most illustrious were H. R. Goeppert (1800-1884), of Silesia; Franz Unger (1800-1870), of Styria; Oswald Heer (1809-1883), of Switzerland; Gaston de Saporta (1823-1895), of France; and C. von Ettingshausen (1826-1897), of Austria. In Britain W. C. Williamson (1816-1895), following the pioneer work of Witham (1833) and Binney (1868), succeeded in placing the anatomical study of petrified plants of the Carboniferous on a solid foundation, and this phase of activity is still assiduously cultivated by a considerable number of contemporary British botanists, among whom D. H. Scott unquestionably stands at the head. In France the most active contributors in recent years have been Bernard Renault (1836-1904) to the anatomical side and C. Rene Zeiller (1847-1916) to all phases of the subject. Probably the most capable of contemporary paleobotanists is A. G. Nathorst, of Stockholm.

The pioneer workers in North America were J. W. Dawson (1820-1899) in Canada and Leo Lesquereux (1806-1889) and J. S. Newberry (1822-1892) in the United States. Unger, in his *Genera et Species Plantarum Fossilium*, had essayed a complete manual of the subject as early as 1850, but a sufficiently large body of facts had not yet been accumulated to give his work lasting value, although it was of immense importance at that time. This task was accomplished by W. P. Schimper (1808-1880) in three volumes of text and one of plates of the *Traité de paléontologie végétale* (1869-1874). A less usable work covering the same field in a different way was the *Paléophytologie*, contributed by Schimper and Schenk to Zittell's *Handbuch der Paläontologie*, which was completed in 1890. More recently, A. C. Seward has essayed to cover the field in a four-volume work on fossil plants (1898-1918), in which little space is devoted to other than the morphological aspects of the subject, and in which the flowering plants are entirely omitted.

METHODS OF PRESERVATION.

Fossil plants have been preserved by two principal methods: They either became waterlogged and were buried in sediment ranging from mud to sand, or were infiltrated by some mineral solution, or were replaced molecularly by silicic acid, calcium carbonate, or other mineral substance. The first method is called inclusion, and the degree with which the details are preserved in the resulting impression depends on the fineness of grain of the sediment. Very

fine muds preserve every detail with great fidelity. Therefore, shales, which are simply lithified muds, furnish beautiful fossils, as in the roofing shales that overlie so many coal seams. The re-deposition of calcium carbonate in the form of travertine often entombs well-preserved plant remains as do the alluvial muds of river flood plains. Volcanic dust falling in water forms an admirable matrix, as in the celebrated Miocene lake deposits at Florissant, Colorado. Impressions of plants constitute the bulk of the objects with which the paleobotanist has to deal. The substance of the inclosed plant fragment may remain as a carbonaceous film; it may be replaced by salts of iron or other mineral; or it may be entirely dissipated, leaving merely the impression. Occasionally lignified remains, such as those from certain localities in the Upper Cretaceous, may retain their internal structure more or less intact, and by special methods may be sectioned and studied microscopically. The fire clays of the Coal Measures often furnish beautiful impressions in dark tints on a light drab background, and some of the light-colored clays of the Upper Cretaceous of South Carolina, where the leaf substance has been replaced by iron oxide, yield handsome red impressions.

Plant remains are often found in a good state of preservation in nodules of iron or calcium carbonate. Coal or lignite beds are simply examples of the inclusion of vegetable *débris en masse*. In coarse sediments, or occasionally in finer materials such as tuffs or travertine, more resistant objects like seeds or stem fragments have left nothing but the cavity or cast, and such objects often furnish satisfactory subjects for study. Amber or other fossil resin has also frequently preserved mummies of plants or other organic remains, especially delicate objects like flowers. The cuticularized integument of pollen grains or spores is very resistant and is frequently preserved. Similarly the cuticles of leaves retaining the outlines of the epidermal cells and the stomata are often found to be intact after the remaining tissues have become completely disorganized. These can sometimes be peeled from the fossils and mounted for microscopical examination, or, if this is impossible, collodian casts of the surface can be made and by the proper handling of the illumination yield satisfactory microscopic details.

The second and third methods of preservation, or more generally a combination of infiltration and replacement, are usually termed petrification. The internal structure of the plant material is conserved with more or less perfection according to the rapidity of permeation before the tissues have rotted and the completeness with which replacement has taken place. If this happened before the tissues became disorganized thin sections may be ground and the

histology elucidated. Petrified woods, especially of coniferous trees, either silicified, calcified, or ferruginized, are common at many geological horizons. More delicate plant fragments are only rarely preserved in this way. Such remains where the replacement has been by calcium carbonate characterize certain horizons of the English Coal Measures, and similar "coal balls" have been discovered more recently in Moravia, Westphalia, and Russia. Silicified plant fossils are found at certain horizons in the Permian of St. Etienne and Autun in France, and often the most delicate thin-walled tissue, such as cambium and phloem, is well preserved. The stumps of Cycadeoidea from the American Lower Cretaceous are silicified, usually denoting a burial in sandy deposits, and range in perfection from those of the Lower Cretaceous of Maryland, which are little more than sandstone casts, to some of the wonderfully preserved stumps of the Black Hills in Wyoming, in which even the embryos in the ovules are completely preserved.

GENERAL PRINCIPLES.

The general principles which paleobotany has elucidated or illustrated can be but briefly indicated. First among these is the fact, roughly traced in the subsequent discussion, that the history of plants shows them to have had a gradual transformation from early simplicity to later complexity and progressive differentiation of both structures and habits in the successively higher groups, thus exemplifying the universal principle of evolution. The original scene of plant activity was in the water. Gradually the main theater of operations was transferred to the land, and the distinction between vascular and cellular plants in this respect is analogous to the distinction between vertebrate and invertebrate animals.

Each successive group of plants that appeared upon the scene illustrates a second great principle—that of adaptive radiation; that is, by progressive modifications (the mutations of Waagen), groups became dominant, such as the Lepidophytes, Arthrophytes, and Pteridosperms of the Carboniferous, the Cycadophytes of the Mesozoic, or the Angiosperms of the Cenozoic, their members became adapted for a great variety of environments and tended to occupy all of the available situations on the land or in cases became secondarily adapted for an aquatic existence, like the water ferns or the various aquatic angiosperms. Paleobotany shows one group after another thus dominating, becoming specialized during the process and then waning or becoming entirely extinct. The accompanying diagram illustrates the successive dominance of different plant types and the increasing complexity of the vegetable kingdom as a whole.

Another principle is illustrated by the progressive loss of plasticity as organisms or organs became complex and specialized. It was the

simpler organisms that outlasted the complex or gave origin to new types. The more complex lost their power of adaptability to change and readily succumbed when such changes in their environment came. For example, it was not the complex arborescent lepidodendroids that gave rise to the modern club mosses, nor were the lofty

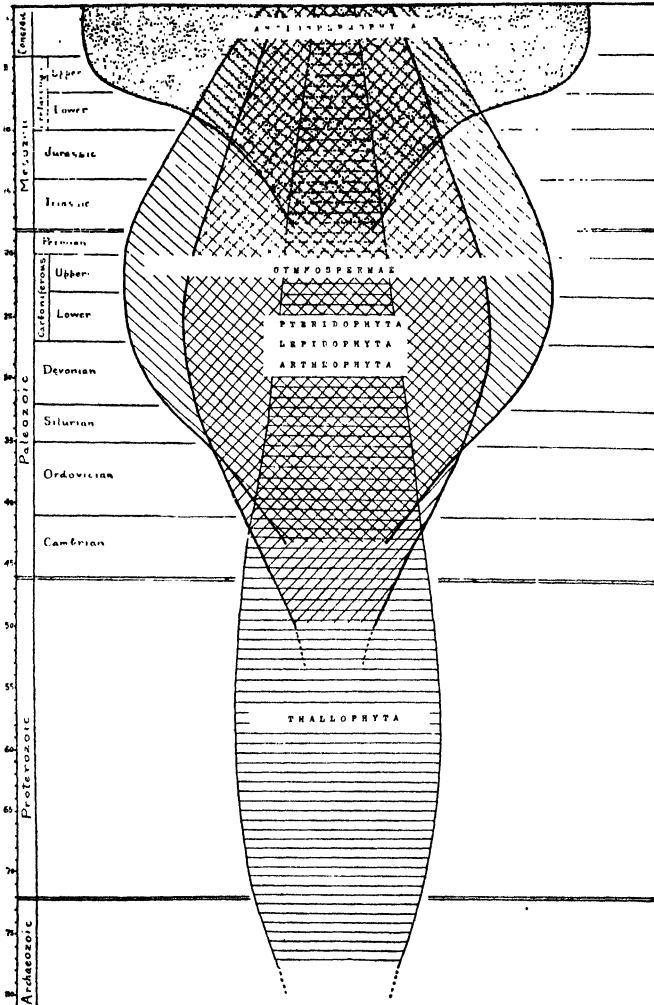


FIG. 1.—Diagram showing the relative duration of geologic time, the successive dominance of plant types, and the progressive increase in complexity of floras.

calamites the progenitors of the modern mares' tails, but in each case simpler forms saved the phylum from becoming extinct. Fern synangia may have given rise to seeds by modification and peripheral sterilization, but no seed has or ever will become modified into a synangium. Thus evolution either of organs or organisms is non-

reversible. The earlier forms of the successive plant groups, in accordance with the *a priori* conclusions of evolutionary philosophy, are in general synthetic or generalized in structure, i. e., they combine features of various categories that subsequently became characteristic of diverging lines of evolution. Thus all of the earlier plants had motile sperms; none had true vessels such as characterize the wood of angiosperms; cryptogamic, or centripetal wood formation was an almost universal feature, and many other similar characters could be mentioned. The Sphenophyllales were synthetic in that they combined certain characters of their fern ancestry with features that subsequently became stereotyped in the Lepidophytes and Calamites; they are thus considered as representing an approach to the common ancestor of the balance of the Lepidophytes and of the Arthropytes. The earliest ferns show combinations of features that subsequently became the property of different fern families; while the Pteridosperms combined the characters of ferns and cycadophytes.

Another principle illustrated by paleobotany is that known as recapitulation, or the fact that, theoretically at least, the ontogeny or development of the individual is an epitomy or abridgment of the phylogeny or development of the race. This principle is, however, difficult of application since its underlying factors are unknown and the ontogeny may show acceleration, modification, or obsolescence that renders the application of recapitulation questionable unless corroborated by other lines of evidence.

A familiar instance of the retention by the seedling of ancestral adult characters is furnished by the conifers, most of which have needle leaves on the shoots of the juvenile forms, while with age these needle leaves of the long shoots are replaced by scales as in an adult pine, or become reduced to conerescent leaves with a cyclic instead of a spiral arrangement as in the juniper, or become reduced to scales while the shoot (phylloclad) functions as a leaf as in Phyllocladus. From these changes in foliage in the earlier part of the life history of the various conifers it is inferred that the scale leaves of *Pinus*, the double leaf of *Sciadopitys*, the phylloclad of *Phyllocladus*, the conerescent cyclic leaves of the Cupressaceae and the deciduous habit of the larch (*Larix*) and bald cypress (*Taxodium*) are all derived characters.

Another principle is derived from the study of persistence of organisms or organs. Such conservative organisms as the Bacteria or the Cyanophyceae have existed unchanged for millions of years. Conservative organs are those like roots, whose functions and environment have remained uniform for ages. Thus all roots are found to be much alike in their organization. Various enthusiasts

have proclaimed the conservatism of the vascular cylinder, while others conceive that the parts concerned with spore or seed formation are more conservative. Foliage in general is apt to be conservative in both form and structure, as witness the similarities in the fronds of the Cycadophytes retained from the Permian to the present, during which their vascular stem structures and especially their fructifications varied through wide limits. Ginkgo leaves have an equally long history, and many angiosperms acquired their distinguishing leaf form during the Upper Cretaceous.

Another general principle derived from the study of the geological distribution of plants—a principle for the most part unrealized by biologists or meteorologists—is that relating to geological climates of which plants are the most satisfactory known tests. The early paleobotanists drew extreme pictures of former vapor-laden atmospheres and tepid, torrid climates, but these are found to have no basis. On the other hand, it has become increasingly clear of late years that the sort of climate under which the history of man has been passed is an abnormal climate from the standpoint of geological history. From the first appearance of terrestrial plants in the Devonian down to the present there are only two periods at which it is possible to distinguish anything approaching climatic zoning. For example, Devonian plants are known from Ellesmere Land on the north to Australia on the south, and no differences are discernable in the floras from latitude 85 and those contemporaneous in central Europe. This uniformity and cosmopolitan distribution continues throughout the Lower and Upper Carboniferous. In the Permian, however, there are well-marked floral provinces succeeding widespread glacial conditions. Again from the late Triassic throughout the Jurassic and Cretaceous there were no polar, temperate, or equatorial zones—the same plants are found within a few degrees of the poles as within a few degrees of the equator. Even in the earlier Tertiary, tropical floras extended halfway across the temperate zones and temperate forests are known from within five degrees of the pole. At the close of the Tertiary the successive glaciations of the Pleistocene changed all this cosmopolitanism, and to-day man is living in a Pleistocene climate, with well-marked climatic zones and seasonal variations. The principle may be stated thus: That for geological time as a whole climates have been more uniform than at present, and marked variations from this uniformity are occasional and are the concomitants of glacial conditions, both apparently the results of a similar but little understood cause.

RELATION TO OTHER SCIENCES.

Paleobotany both contributes to and borrows from the other earth sciences. Its relation to botany in the accepted sense of that term

is peculiar, since paleobotany is the botany of all geological time, while botany is that of but one geological period—namely, the present. It is now quite impossible to obtain a broad foundation for phylogenetic, morphological, or distributional studies of existing plants without a consideration of their extinct ancestors. In the interpretation of the far distant past paleobotany and its sister science paleozoology contribute fundamental data to geology, not only in furnishing the “medals of creation,” which constitute the best basis for a geological chronology yet discovered; not only as comprising the subject matter of the biology of the past, which is a legitimate part of earth history, but in the elucidation of the climate and other physical conditions of past times, subjects which may be embraced under the terms of Paleoclimatology and Paleocology. Paleogeography, or the Physical Geography of past times, also derives some of its most important facts from the study of the character and distribution of fossil organisms.

TYPES OF VEGETATION.

The salient features of the various phyla into which the vegetable kingdom is now divided will be passed in review, after which the evolution of floras from the beginning of life on the globe down through the Pleistocene will be briefly sketched.

PHYLUM THALLOPHYTA.

As a convenience and because of their lack of importance as fossils the old term Thallophyta will be used for the great mass of thallus plants, formerly thought to constitute a single subkingdom but now known to represent several phyla. The thallophytes embrace plants of the simplest type, but they exhibit nevertheless a very wide range in the structure and degree of differentiation of the vegetative body and in their methods of reproduction. The plant body may be a single minute and often motile cell multiplying by fission, or the thallus may be an aggregate of cells with a well-marked physiological division of labor, and differentiated into parts analogous to the roots, stems, and leaves of the higher plants, and with a corresponding histological complexity. The best known thallus plants [to the nonbotanist] are bacteria, such fungi as molds and toadstools, and seaweeds. With but few exceptions, marine plants are thallophytes, although immense numbers are also found in fresh water and in various terrestrial habitats. In general, the larger and more complex are marine and some of these are among the most gigantic of plants.

The thallophytes are primitive types and their existence unquestionably antedates the geological record, although they are now known in considerable variety from pre-Cambrian. They furnish little that is of paleobotanical interest, since they are either so slightly

resistant that they have left only illy defined impressions in the rocks, or, if they had hard parts as in the so called calcareous algae, these, while they are often abundant, as in the various limestones of Paleozoic, Mesozoic, and Cenozoic age, add little to the knowledge obtained from a study of existing forms. They are, however, of great philosophic interest, since they point to the steps in the evolution of the first life forms and since also they are unquestionably the ancestors of the land plants which appear in the Devonian records and from which all of our existing terrestrial vegetation has been evolved. A few of the more important fossil types will be briefly enumerated.

Proterozoic algae are represented by the large concentrically laminated calcareous deposits known as Cryptozoon, as well as by other forms referred by Walcott to the genera Weedia, Collenia, Newlandia, Kinneyia, Greysonia, etc. Thousands of obscure tracings in the Paleozoic and later rocks have been described as fossil seaweeds, but large numbers of these supposed fucoids have been shown to be the casts of trails, burrows and similar tracks of worms, trilobites, and other marine organisms, while others are rill or current markings of nonorganic origin. Nevertheless, there is no reason for doubting the presence of algae from the pre-Cambrian onward, particularly when the supposed fossils show a carbonaceous residue as in the genus *Spirophyton* of the middle Devonian. The genus *Nematophycus* of the Silurian and Devonian includes gigantic forms with their internal structure preserved, the silicified stems of *N. logani* being sometimes several feet in diameter. *Nematophycus* has been regarded as belonging to the Siphoneae or possibly the Phaeophyceae (brown algae).

Another undoubted member of the latter group is the upper Devonian genus *Thamnocladus*. The Diatomaceae (Bacillariaceae), whose siliceous frustules accumulate as oozes in the present marine and fresh waters, occur as fossils from the lower Jurassic onward. They are sometimes present in the Tertiary as relatively pure beds many feet in thickness and made up of billions of tests of these tiny forms, as in the Miocene Calvert formation of Maryland and Virginia, or in the Pliocene of California. The Chlorophyceae or green algae include many doubtful fossil forms and numerous others that are well authenticated, particularly in the somewhat unique group of Siphoneae. Joints of the verticillate or tubular calcareous forms occur in the older Paleozoic (Cambrian to Silurian), where they are represented by the genera *Ascoma*, *Primicorallina*, *Sycidium*, *Callithamnopsis*, etc. This type becomes exceedingly common at certain Mesozoic and Cenozoic horizons, as in the Mediterranean-Triassic (*Diploporella*, *Halorella*, *Triploporella*) or the middle Eocene of the Paris basin.

Associated with the foregoing are species of Codiaceae (*Girvanella*, *Sphaerocodium*, *Halimeda*, *Ovulites*), Dasycladaceae (*Aicularia*, *Cymopolia*, *Vermiporella*, *Diplorella*, *Gyroporella*). The Characeae, or Charophyta as they are sometimes called, are a somewhat isolated group of fresh and brackish water forms, the stoneworts. They are doubtfully recorded from rocks as old as the Devonian and their calcareous fruits (oogonia) are present in considerable abundance throughout the Mesozoic and Cenozoic. The Rhodophyceae (Florideae), or red algae, include one family, the Corallianceae, that is of considerable geological importance, being represented as early as the Ordovician by *Solenopora*, and common throughout the Mesozoic and Cenozoic (*Lithothamnium*, *Lithophyllum*). These are the nullipores or reef-forming types and some of them are remarkable in that they contribute as much as 25 per cent of magnesium carbonate to the resulting reefs.

Paleozoic bacteria have been known since 1879, and a considerable number of supposed species have been described by Renault. Proterozoic bacteria have recently been described by Walcott, who believes that pure limestones without traces of organisms other than algae clearly indicate the presence of bacteria as the active agents of precipitation through their denitrifying activities. Traces of fungi are commonly met with from the Devonian onward. These are usually in the form of mycelial hyphae, both nonseptate (*Phycomycetes*) and septate (*Mycomycetes*). They occur in fossilized plant tissues, and occasionally the minute spores or traces of oogonia or sporangia are present. Berry has recently described forms in petrified Eocene palm wood in which various stages of sporangial growth and spore formation are preserved (*Peronosporoides*). Other specimens show zygospores or conidia (*Zygosporites*, *Cladosporites*, *Haplographites*, *Oochytrium*, etc.)

Foliage preserved as impressions frequently shows traces of leaf spot or other fungi, and many undoubted remains of this sort have been described. All of these types of fungal remains are exceedingly common at all horizons where petrified or other plant tissues occur, but their nature largely precludes systematic study. It can be safely asserted that the fungi were of very ancient origin and were already present in great variety in the older Paleozoic, but that their perishable nature and nonaquatic habitat has prevented large numbers from becoming preserved as fossils. Microscopic forms of both algae and fungi are present in abundance in oil shales and in some bog ores of iron from the Silurian down to the present time.

PHYLUM BRYOPHYTA.

The Bryophyta or moss plants, comprising the existing mosses and liverworts (*Hepaticae*), which occupy so prominent a place in some

evolutionary schemes, are almost entirely unknown as fossils and such as are known are either inconclusive in character or confined to relatively recent periods. These plants were never of large size, nor have they ever become truly fitted for terrestrial existence. Their absence in the geological record can not be attributed to their perishable nature since much more delicate objects have been abundantly preserved at various geological horizons. While they have been recorded from the Paleozoic, especially by the early students, these records usually resolve themselves into fragments of *Lepidophyte*, *Arthrophyte*, or *Coniferophyte* foliage. None are conclusively known earlier than the Mesozoic, and the liverworts antedate the true mosses in the record, fruiting and therefore conclusive material of the latter group being unknown in rocks older than the Tertiary.

PHYLUM PTERIDOPHYTA.

The term *Pteridophyta* as here understood is restricted to the fern phylum—the *Filicales* of the older students—the so-called fern allies (club mosses and horsetails) being grouped in the phyla *Arthrophyta* and *Lepidophyta*. The *Pteridophyta* are a very ancient stock, always megaphyllous and phyllosiphonic. The fructifications are borne upon but slightly modified foliage leaves and were never strobiloid. The known forms are prevailingly homosporous, although heterospory must have been evolved early in their history since the *Pteridosperms* are clearly derived from the ancient, at least pre-Devonian, fern stock. Among existing ferns the *Hydropterales* or so-called water ferns, of somewhat questionable relationships, are also heterosporous.

Living ferns are usually segregated into two major groups—the *Eusporangiate* and *Leptosporangiate*, according as the sporangium develops from a group or from only a single cell. While this distinction is not without exceptions it is one not observable in fossils, where the mature features must be relied upon. On the whole the *Eusporangiate* sporangia are large, attached by a broad base, with a wall more than one cell thick, and without a definite annulus, though some of the cells may be thickened; moreover in the *Marattiales*, one of the important orders from the paleobotanical viewpoint, the sporangia are united to form synangia, which by some students are thought to represent a modification of the sporangio-phore so prominent in the *Arthrophyta*, and vestigial in the *Lepidophyta*. In the present treatment the *Pteridophyta* are segregated into the four classes, *Coenopteridae*, *Eusporangiatae*, *Leptosporangiatae*, and *Hydropteridae*, which will be considered separately.

The *Coenopteridae* or *Primofilices* comprise a group of Paleozoic ferns known almost entirely from the anatomy of stems and petioles,

the features of which are probably overestimated in discussing their interrelationships. The name, derived from the Greek root for common or general, is adopted in allusion to their synthetic characters, and the group is considered to have been much wider than is indicated by our knowledge of the two families Botryopteraceae and Zygopteraceae, and in the accompanying phylogenetic diagram is used as the starting point of the fern phylum.

Without attempting to formulate the theoretic characters of the Eofilices or setting diagnostic bounds to the Coenopteridae as here

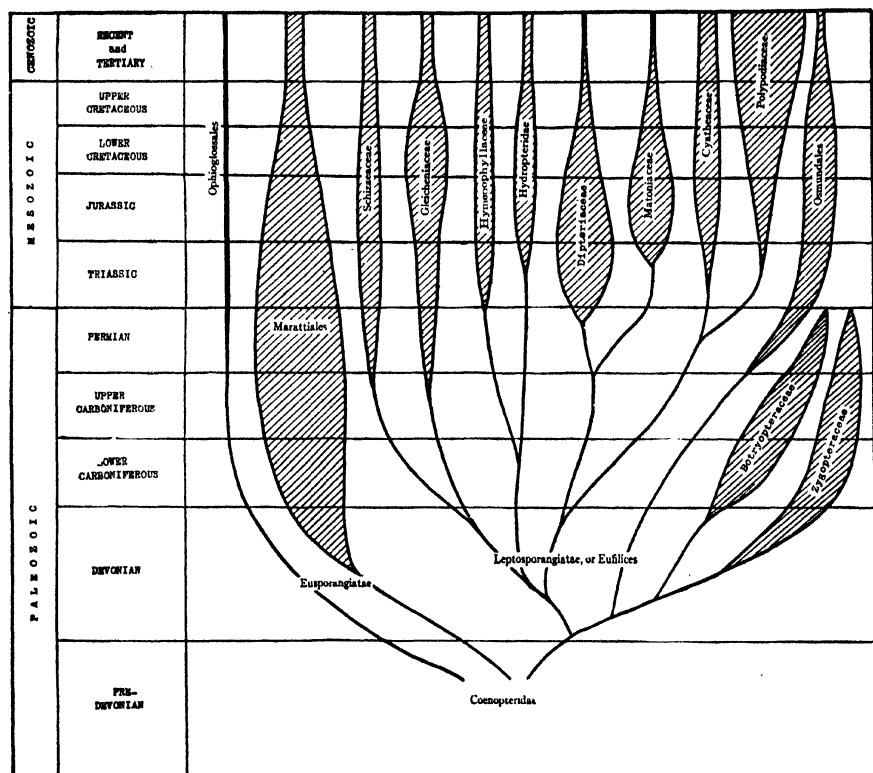


FIG. 2.—Diagram showing the geologic history and interrelationships of the ferns.

used, we may pass to a brief consideration of the two known families.

The Botryopteraceae at present embrace three genera: *Grammatopteris* and *Tubicaulis* based upon Permian stem anatomy, and *Botryopteris* based upon stem and sporangial structural remains ranging in age from the Lower Carboniferous to the Permian. Little is known of the habits of fronds of these types and they have not been definitely correlated with material preserved as impressions. They had slender monostelic stems exarch in *Grammato-*

pteris and *Tubicaulis*, endarch in *Botryopteris*, with scalariform or reticulate tracheids. In *B. forensis* the sporangia were pedicellate in groups of from two to six on the ultimate divisions of compound fronds. They were pyriform with walls of two layers of cells and on one side had an annulus several cells in width suggesting comparison with the *Osmundales*. The leaf traces vary from rectangular in *Grammatopteris* and oval in some species of *Botryopteris* to omega shaped in other species of that genus. All known *Botryopteraceae* were small plants thought to have had slightly fleshy pinnules, and abundantly clothed with epidermal hairs.

The family *Zygopteraceae* is based largely on a variety of structural remains of petioles, although the stem anatomy and sporangial structure are known in several instances. They range in age from the Devonian (*Clepsydropsis*) to the Permian. The leaf traces show a variety of complexities of form and histology, and in cross section range from an hourglass or H-shape to the stellate form of *Astrochlaena*. It seems probable that the elaborate classification which Bertrand has based on the variations of these petiolar strands would not survive a knowledge of the other characteristics of these ancient types.

The sporangial characters show considerable variation. In *Zygopteris* the sporangia were grouped and annulate much as in *Botryopteris*. In *Diplolabis* and *Stauropteris* an annulus was not developed; the former had the sporangia grouped in sori or synangia while in the latter they were borne singly on the ultimate divisions of the frond. The class as a whole shows relationships with the *Ophioglossales*, *Osmundales*, and *Marattiales*.

The Eusporangiate class of ferns comprise two known orders—the *Ophioglossales* and *Marattiales*, the former regarded as very primitive by most students and but slightly represented in the fossil state, although the Paleozoic *Rhacopteris* and *Ophioglossites* and the Mesozoic *Chiropteris* have often been considered as representing this order.

The *Marattiales*, on the other hand, with six existing genera and about 30 large handsome tropical and subtropical species, have an extended geological history. In the present state of our knowledge, confused as it is by the resemblance of *Pteridosperm* microsporangia to *Maratteaceous* synangia, it is difficult to give a satisfactory estimate of the relative importance of the *Marattiales* in the Paleozoic, but they certainly occupied a prominent position. In those early floras and this prominence rests on the evidence of the cosmopolitan frond genus *Pecopteris*, the stem anatomy of the forms referred to *Psaronius* and its allies, and upon a variety of fructifications.

The *Psaroniaceae* were tree ferns sometimes 50 feet or more tall, with fronds, in cases where actual connection has been established,

of the Pecopteris type, arranged in crowded spirals (*Psaronius poly-stichi* = *Caulopteris impressans*), in four vertical rows (*Psaronius tetrastichi*) or in two opposite vertical rows (*Psaronius distichi* = *Megaphyton impressans*). Specimens of *Psaronius* were probably the earliest known fossil plants with structure preserved since polished slabs of the trunks were in considerable vogue during the eighteenth century as decorative objects under the names of "staarsteine" or starling stones because of their speckled appearance (*Psaronius* has the same meaning), dependent on their anatomical structure. A very large number of species have been described from the Upper Carboniferous and Permian. They have been favorite objects of histological investigation since the days of Corda (1845); since they are common in a petrified condition in Saxony, France, and elsewhere. Anatomically, the stems have a complex system of laterally elongated, concentric curved steles of scalariform tracheids surrounded by phloem and immersed in a parenchymatous ground mass with some sclerotic bands below the leaf gaps.

Some of the polyarch roots show secondary wood, but none has been observed in the stems, the central one cauline and the outer ones giving off numerous leaf traces and adventitious roots. Outside the sclerenchymatous region which bounds the stem proper is a very broad zone, formerly thought to be cortical, consisting of closely packed adventitious roots embedded in a dense felt of hairs which spring from both the stem and the roots.

The petioles usually show a single horseshoe-shaped trace, although sometimes a second lies within the first. The occasional presence of lacunae in the root cortex of some of the species suggests a swampy substratum.

Pecopteris fronds represent the one type among the many familiar fern-like fronds of the Paleozoic which are so abundant in the roofing shales of the coal seams that is frequently found in a fruiting condition. Some have been demonstrated to have been borne upon *Psaronius* stems and this is probable of the majority. The fructifications are of a variety of types. Those known as *Asterotheca* had large synangia in two rows, one on either side of the median vein on the under surface of the pinnules, each consisting of five or six sac-like confluent sporangia forming a close ring. Other confluent synangia known as *Ptychocarpus* characterize an Upper Carboniferous and Permian series of Pecopterids. These synangia consist of five to eight sporangia united laterally to form a close ring and adherent to a central receptacle and embedded in continuous enveloping tissue. They discharge their very numerous small spores through apical pores, and greatly resemble the arrangement in the modern genus *Kaulfussia*. A third Paleozoic type is *Danaeites* and

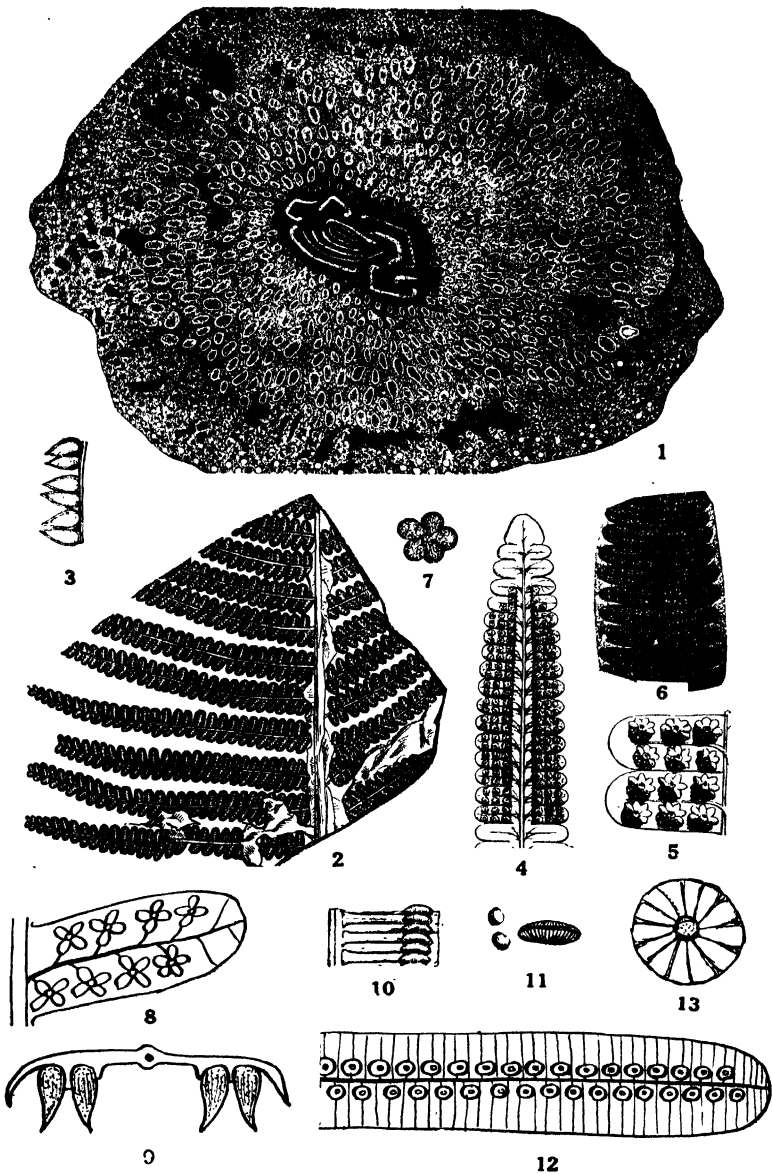


FIG. 3.—Stem anatomy, foliage, and fructifications of the Paleozoic and Mesozoic Marattiales.

1. *Psaronius cotta* Corda. Cross section of stem from the Permian of Saxony (after Corda).
2. *Pecopteris arborescens* (Schlotheim). A Carboniferous and Permian frond type (after Schenk).
3. Magnified section of sori of *Asterotheca cyathea* Brongn.
4. Fertile pinnae of *Pecopteris unita* Brongn., with *Asterotheca* fructifications (after Grand'Eury).
5. Two pinnules of preceding enlarged.
6. *Asterotheca hemitelioides* Brongn. (after Grand'Eury).
7. A sorus of the preceding, enlarged.
8. Underside of pinnule of *Scolopopteris elegans* Zenker from the Permian of Saxony.
9. Transverse section of preceding, enlarged (after Strasburger).
10. Fragment of fertile pinna of *Marattia muensteri* (F. Braun) from the Rhaetic of Bavaria.
11. Synangium and spores of preceding, enlarged (after Schimper).
12. *Nathorstia angustifolia* Heer, from the Lower Cretaceous of Greenland, enlarged (after Heer).
13. A synangium of preceding, $\times 8$ (after Nathorst).

Parapeopteris, in which each pinnule bore two continuous rows of ovoid sporangia more or less united and embedded in the lamina and opening by apical pores. A fourth type known as Scoleopteris shows the sori in two rows and consisting of four or five long-pointed pendant sporangia more or less confluent proximad, united internally for about one-third their length to a central stalk, suggestive of the modern genera *Marattia*, *Kaulfussia*, and *Angiopteris*, particularly the first.

Other fructifications (*Grand'Eurya*, *Dactylothea*) have partially or entirely free exannulate sporangia. Many other supposed Marattiaceous fructifications have been described from the Paleozoic rocks, as, for example, *Hawlea* in which there is a rudimentary annulus, *Urnatopteris* in which the fronds were dimorphic, *Renaultia*, *Sphyropteris*, and *Discopteris*.

The Marattiales are represented in Triassic floras by numerous widespread forms variously referred to the genera *Marattia*, *Marattiopsis*, *Angiopteridium*, *Angiopteris*, *Danaea*, *Danaeopsis*, *Pseudodanaeopsis*, *Asterotheca*, *Taeniopteris*, and *Macrotaeniopteris*. They occur on all the continents and make a particularly large display in the late Triassic (Keuper and Rhaetic), at which time palustrine, often coal-forming, conditions with apparently identical species of plants occur from the Arctic to the Antarctic and from Tonkin and Australia to Virginia, California, and Chile. The identity of these Triassic Marattiales with existing forms rests on the form and venation of the fronds, the arrangement and structure of the sporangia, and even the spores.

The Marattiales were less dominant in the overlying Jurassic, and they were still more reduced during the Lower Cretaceous (*Angiopteridium*, *Nathorstia*, *Taeniopteris*?). *Nathorstia*, with several Greenland and Bohemian species shows pinnate fronds with narrow entire pinnules bearing two rows of circular synangia of radially arranged sporangia united to a central receptacle.

Subsequent to Lower Cretaceous times Marattiaceous remains are infrequent, although occasionally brought to light in the Upper Cretaceous and Tertiary. A *Marattia* is described from the English Eocene and a second from the French Oligocene.

The order Osmundales includes the two recent genera *Osmunda* and *Todea*, together with a dozen or 15 species with large sporangia arranged in small groups, in linear and often confluent sori, or clustered around the axis of the much reduced fertile pinnae. An annulus is represented by a group of thick-walled cells below the apex. These stand somewhat apart from the balance of existing ferns and are wide-ranging forms, some of which are found on all the continents, *Osmunda* being cosmopolitan and *Todea* antipodean. Aside from

morphological considerations, the evidence that the Osmundales constitute a relatively primitive line of fern evolution is furnished by impressions like *Todea Lippoldi* Stur from the Lower Carboniferous of Silesia, petrified sporangia such as *Todeopsis primaeva* Renault from a similar French horizon, or *Sturiella* from the German Upper Carboniferous, and finally by the phylogenetic series of petrified stems described by Kidston and Gwynne Vaughan, among which the genera *Bathypteris*, *Anomorrhoea*, *Thamnopteris*, and *Zalleskya* come from the Upper Permian (Thuringian) of the Ural region. Space does not permit a description of their histology, but it may be pointed out that the order appears to have been derived from an ancestor with a solid stele like the Coenopteralean species *Diplolabis Roemeri* and to have undergone an evolution more or less paralleling that of the *Zygopteraceae*. This line is continued by Jurassic and Lower Cretaceous species of *Osmundites* from South Africa, New Zealand, and Canada, and by Tertiary species from England, South America, and Hungary. Impressions of both sterile and fertile fronds allied to *Todea* are abundant and cosmopolitan in the late Triassic and Jurassic and continue into the Cretaceous, while *Osmunda*-like frond forms are common throughout the Lower and Upper Cretaceous and Tertiary in all parts of the world.

A class of ferns, including the existing heterosporous *Rhizocarps*, or so-called water ferns, includes the order *Hydropterales* and possibly an extinct order, the *Sagenopterales*. The two existing families, *Marsiliaceae* and *Salviniaceae*, are small, more or less widespread aquatic forms with dioecious prothalli, exannulate sporangia inclosed in "sporocarps," which are modified frond segments or highly developed indusia. Only a single megaspore reaches maturity in each megasporangium. The *Salviniaceae* contain the genera *Azolla* and *Salvinia* with between 15 and 20 existing species of the warmer regions and the leaves of the latter genus not appreciably different from those of the existing species are found throughout the Tertiary period.

The *Marsiliaceae* consist of three genera—the monotypic Brazilian *Regnellidium*, *Pilularia* with about six species and *Marsilia* with over 50 widely distributed existing species. The last has been found fossil as early as the Upper Cretaceous, but is rare and more or less uncertain in the fossil state. The extinct genus *Sagenopteris* is based for the most part on groups of two to five large asymmetrical reticulate veined pinnules borne digitately at the apex of a long and rather stout stipe and found as impressions in the late Triassic (Keuper and Rhaetic) very common in the late Triassic and basal Jurassic (Liassic) with seven or eight species rather widespread during the Lower Cretaceous and surviving in one or two Upper

Cretaceous species. Associated with some of the older forms are oval or spherical bodies thought to represent sporocarps.

The remainder of the living and fossil ferns, excepting certain illy understood extinct types, such as the Devonian and Lower Carboniferous Archaeopteridae and the Mesozoic Tempskya, may be grouped together in the Leptosporangiate or Eufilicalean order Polypodiales, although there is some evidence for recognizing the Gleicheniales and Matoniales as independent orders.

The Polypodiales embrace the great majority of living ferns and include the most specialized and abundant families. Without taking the space to give their diagnostic characters, which appertain more especially to the study of recent forms and are admirably discussed in many texts devoted to that subject, it will be desirable as well as interesting to glance at the geological record of the various families.

The family Schizaeaceae with between 75 and 100 existing, mostly tropical species, segregated into the genera Schizaea, Lygodium, Mohria, and Anemia, appears to be present as early as the upper Carboniferous in the genus *Senftenbergia* of Corda, which had small linear pinnules bearing two rows of solitary sessile sporangia, with apical annulae of four or five rows of cells. Triassic forms are not certainly recognized, but the Jurassic genus *Klukia* with tripinnate fronds shows fructifications that render its reference to this family conclusive. Some of the form-genus *Cladophlebis* (e. g., *C. Browniana* from Peru) appear to belong to this family, and during the Lower Cretaceous the genus *Ruffordia* of Europe and America appears to represent the genus *Anemia*, while *Schizaeopsis*, found in a fruiting condition in the Lower Cretaceous of Virginia, represents *Schizaea*. The genus *Acrostichopteris*, based upon sterile fronds, which range from the bottom to the top of the Lower Cretaceous, and found in both Europe and America, also almost certainly represents an extinct type belonging to this family. In the Upper Cretaceous petrified sporangia of the *Schizaea* type have been found in Japan (*Schizaeopteris mesozoica*). Undoubted species of *Anemia* and *Lygodium* in Europe and America are common and widespread during the Tertiary, the latter genus being often found in fruiting condition. In the poleward spread of subtropical floras in the Eocene and early Oligocene, *Lygodium* is found as far north as the south of England, Wyoming, and Kentucky, associated with *Acrostichum* and other tropical forms.

The family Gleicheniaceae embraces about 100 tropical and subtropical gregarious species now segregated to form the genera *Gleichenia*, *Platzoma*, *Dicranopteris*, and *Stromatopteris*—the last monotypic on New Caledonia and *Platzoma* monotypic in northern Australia.

Gleichenias all grow in thickets; the foliage is coriaceous and perennial and the growth indeterminate. The fronds branch dichotomously and resume growth season after season, so that in some cases the fronds are said to be over 100 feet in length. The pinnae are pinnatifid with small ovate segments or elongate pectinate pinnales. Primitive foliar characters are the dichotomous habit and the frequent development of subsidiary pinnae between the normal ones. Sori subglobose, comprising two to six nearly sessile sporangia, found on the back of a vein. Each sporangium is surrounded by a broad, transverse equatorial annulus and opens vertically. Spores are ovoid or tetrahedral, without chlorophyll and with a single dorsal line.

The existing species range from China and Japan to New Zealand, Tasmania, and South Africa in the Eastern, and from Louisiana to the Straits of Magellan and the Falkland Islands in the Western Hemisphere. While largely tropical, temperature is apparently not an important factor, since they occur at high elevations in the Andes and elsewhere, and range southward to the bleak country of the Straits of Magellan. Moisture seems to be the most important factor, for while the foliage is more or less xerophytic, they do not grow outside regions of abundant rainfall or great humidity. They are common throughout Oceania, being especially abundant in the Hawaiian Islands. Their present distribution is clearly indicative of a geological history, and fortunately considerable of this history is known. The family is evidently an old one and appears to be present as early as the Carboniferous in the genus *Oligocarpia*, which had sphenopteroid foliage and circular sori consisting of from six to ten pyriform sporangia with a complete transverse annulus (Zeiller 1888, vide Scott, 1908). The Carboniferous genus *Gleichenites* Göppert and the dichotomous branching genera *Mariopteris* Zeiller and *Diplothemema* Stur are all now considered as probable Pteridospermophytes and it is evident that the *Gleichenoid* habit of growth was common in both Paleozoic and Mesozoic, and is without special bearing on botanical relationship.



FIG. 4.—*Gleichenia heerii* Berry from the upper Triassic of Switzerland. $\times 5$.

The family is not known to have been abundant in the Triassic or Jurassic, the Keuper genus *Mertensides* of Fontaine being often referred to the Marattiales. A species of *Gleichenia* with well marked fruticulations is, however, recorded from the Keuper of Switzerland and the genus is known from the Rhaetian of Franconia. Jurassic species are recorded from California, India, Italy, and Poland. Throughout the Cretaceous *Gleichenia* becomes almost world-wide in its distribution. While the number of species has

probably been excessively multiplied, the records show 15 Lower Cretaceous forms. These include Greenland, Spitzbergen, California, and Virginia, and the great display of that time was in western Greenland.

No less than 25 different species have been recorded from the Upper Cretaceous and the localities include Greenland, Atlantic coast of North America from Marthas Vineyard to Alabama; Kansas, Colorado, Wyoming, and British Columbia in the west; Bohemia, Moravia, Saxony, Rhenish Prussia, and Bulgaria in Europe; and New Zealand, Sachalin Island on the east coast of Asia. *Gleichenia* becomes much less abundant in the Tertiary and all of the known Tertiary records are pre-Miocene. Four species are known—two Oligocene species in Saxony, an Eocene or Oligocene species in Nevada, and a middle Eocene species in the south of England.

The family *Matoniaceae* with but two existing species of Borneo and the Malay Peninsula was prominent in older Mesozoic floras from the Upper Triassic through the Jurassic, at which time it was represented by a variety of widespread species referred to the genera *Lacopteris* and *Matonidium*. Still more interesting is the family *Dipteriaceae* with the single existing genus, *Dipteris*, with but four species confined to the Malayasian region and found growing in association with *Matonia*.

The *Dipteriaceae* became dominant slightly earlier than the *Matoniaceae*, and the magnificent lyrate fronds of some of the species are exceedingly common in the Triassic, at which time the genera *Dictyophyllum*, *Clathropteris*, *Thaumatopteris*, and *Camptopteris* are represented. They had lyre-shaped fronds of large size, consisting of many separate or slightly united, serrate margined, and netted veined pinnules, arranged digitately on a forking stipe; and annulate sporangia much like the existing *Dipteris*. The striking appearance of these forms is better illustrated by the accompanying restorations than they would be by any amount of descriptive text. *Clathropteris* and *Dictyophyllum* survived into the succeeding Jurassic, where they were on the wane, becoming replaced in the Cretaceous by forms more like the modern *Dipteris* and referred to the genus *Protorhipis* (*Hausmannia*). The sketch map (fig. 5) shows the cosmopolitanism of the family in the Mesozoic and the restricted distribution of the few existing species. Restorations are shown in figs. 32-34.

The family *Hymenophyllaceae*, comprising the existing filmy ferns, is practically unknown in the fossil record although several Paleozoic genera (*Hymenophyllites*, *Rhodea*, *Acrocarpus*) have been referred to it upon insufficient grounds.

Without mentioning the various small modern families unknown in the fossil state, there remains the two families *Cyathaceae* and *Polypodiaceae*. The former are almost exclusively tree ferns in the

modern flora. They are represented in the Mesozoic by *Coniopteris*, *Dicksonia* and *Thyrsopteris*, to which *Dennstaedtia* is added in the Tertiary.

The Polypodiaceae, which comprise the bulk of existing ferns and exhibit a very great variety in form and habit, are relatively modern. Some at least of the older Mesozoic species which are referred to the form genus *Cladophlebis* belong to this family. *Cladophlebis* which appeared in the Triassic became cosmopolitan in the Jurassic and Lower Cretaceous where it was associated with species of *Onychiopsis*, *Asplenium*, *Dryopteris*, etc. *Pteris*, *Onoclea* and other genera are added in the Upper Cretaceous, and a great variety of generic types

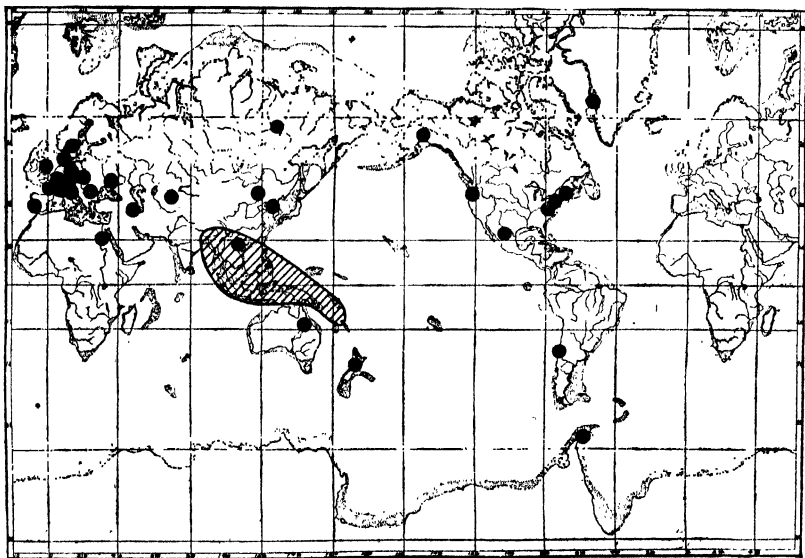


FIG. 5.—Sketch map showing the existing range and the geologic occurrences of the Dipterocarpaceae.

appear in the Tertiary (*Adiantum*, *Polypodium*, *Acrostichum*, *Oleandra*, *Woodwardia*, etc.)

PHYLUM ARTHROPHYTA.

The Arthrophyta constitute a well-marked phylum and comprise plants ranging in size from herbaceous forms to large trees and found from the oldest horizons containing land plants down to the present. They are characterized by invariably articulated and pre-vaillingly ribbed stems, with the leaves in whorls (verticillate) at the nodes, free or more or less connate, dichotomously compound in the earlier groups (*Pseudoborniales*, *Protocalamariaceae*), palmately lacinate in some *Sphenophylleae*, progressively reduced during the history of the phylum until in the modern forms the stems and

branches perform most of the photosynthesis. They are all sporangiophoric and strobiloid, although there is a considerable range of variation in morphological and histological details. Some are homosporous and others heterosporous.

The phylum is unique in that it attained its maximum development in the Paleozoic and has been practically unrepresented since Triassic times except by the single genus *Equisetum*, which survives to the present with less than two score ubiquitous and rather uniform species. The stock appears to have been of Pteridophytic origin and to have been primitively megaphyllous. Taxonomically it corresponds rather closely with the *Articulatae* of Lignier and the *Sphenopsida* of Scott. As known at the present time, it consists of two classes—the *Sphenophyllae* and the *Calamariae*, and the latter includes three rather well-defined groups or orders, namely, the *Pseudoborniales*, the *Equisetales*, and the *Calamariales*, the last including two families, the *Protocalamariaceae* and the *Calamariaceae*.

The most primitive of these subordinate groups constitutes the single order *Sphenophyllales* of the class *Sphenophyllae*. This was a synthetic alliance of mostly small forms that combined certain fern characters with those of the *Calamariae* on the one hand, and the *Lepidophyta* on the other. They are regarded as representing the specialized descendents of a pro-*Sphenophyllum* stock, which was more truly intermediate between the *Arthrophyta* and *Lepidophyta*, and which is supposed to have flourished in pre-Devonian times. The *Sphenophyllums* ranged from the Devonian to the Permian and were practically cosmopolitan except for their partial extinction in Gondwana land during and immediately subsequent to the Lower Permian glaciation. They comprise a considerable number of rather uniform species, based for the most part upon the impressions of the slender jointed ribbed stems with nodal whorls of cuneate leaves (hence the generic name), and long familiar to paleobotanists.

Their habit was much like that of a modern *Galium*, although the genus *Cheirostrobus*, based upon structural cone material, suggests that they were not invariably small, weak-stemmed, clambering forms. The ribs did not alternate at the nodes, and consequently the leaves of successive whorls were superposed and not alternating. The leaves, normally six to a whorl and cuneate, with entire or toothed apical margins, were frequently dichotomously lacinate, and in some forms with numerous narrow leaves in each whorl, these are legitimately regarded as corresponding to the lacinate segments of the digitately leaved species. The stems branched frequently at the nodes. The fructifications were fairly large cones, superficially resembling those of calamites.

The stem anatomy, the elucidation of which we owe in the first instance to Renault, was characteristic and sufficiently unique. In

the center there was a triangular strand of primary wood without any pith or parenchyma and either triarch or hexarch in structure, with the protoxylem or primitive spiral elements at the angles and centripetal in its development. The spiral elements sometimes pass into reticulate tracheids and the later and more central tra-

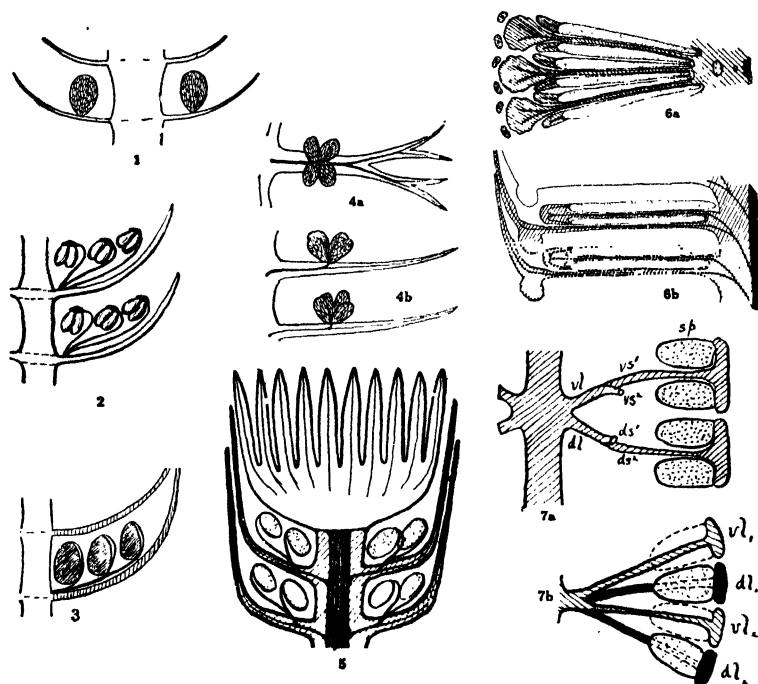


FIG. 6.—Types of fructifications of the Sphenophyllales.

1. *Sphenophyllum trichomatosum* (after Stur).
2. *Bowmannites roemeri* (after Solms).
3. *Sphenophyllostachys* (after Zeiller).
- 4a. *Sphenophyllum majus* from above (after Kidston).
- 4b. Two nodes of preceding from the side (after Kidston).
5. *Sphenophyllum dawsoni* showing two whorls in median longitudinal section and external view of a whorl of bracts (after Scott).
- 6a. Diagram of transverse section of a complete sporophyll of *Cheirostrobos* (after Scott).
- 6b. Diagram of median longitudinal section (after Scott).
- 7a. *Sphenophyllum* fertile, median longitudinal section at a node (after Scott): v1, ventral lobe of sporophyll; vs1, vs2, segments into which it splits; d1, dorsal lobe of sporophyll; ds1, ds2, segments into which it splits.
- 7b. Diagram of a single sporophyll as it would appear in a transverse section of the cone (after Scott): v1, v11, ventral lobes; d1, d11, dorsal lobes.

cheids are pitted. Secondary wood formation commenced early in the ontogeny by the activity of a normal cambium. The secondary wood had its elements very regularly arranged and consisted of radial series of large tracheids with bordered pits, chiefly on their radial walls. Interspersed among the tracheids were vertical strands of parenchyma connected radially by short cells or strands

that did not form continuous medullary rays. Beyond the normal cambium was the phloem surrounded by internal periderm formed by a phellogen, first in the cortex and subsequently passing inward until it arose in the phloem itself. In *Sphenophyllum insigne*, a Lower Carboniferous form of Britain and Silesia, the stem was rather larger than the average, although still not over a centimeter in diameter, and differed in having continuous medullary rays, so that the complicated system of vertical and radial parenchyma of the later forms may have been a derived rather than a primitive feature.

The leaf anatomy presents no unusual characters except its strong mechanical construction, thus precluding the idea advanced by some botanists that the sphenophyllums were aquatic forms. The root anatomy shows no features of special interest.

At least seven types of cone organization are known, indicating generic differences unsuspected from the external appearance or vegetative habits of the plants. In fructifications of the *S. dawsoni* and *S. cuneifolium* type, the slender cones consisted of a central axis with whorls of proximally connate bracts, the latter with long imbricated pointed tips. Each bract bore two slender—one long and the other short—stalked sporangiophores, so that there were two concentric series to each whorl of bracts. A single pendulous sporangium was borne at the tip of each sporangiophore. The spores were somewhat variable in size, which has been interpreted as indicating incipient heterospory, and appear to have been all of one kind. A second type, described from the Polish Carboniferous as *Bowmannites roemeri*, had similarly connate whorls of imbricated bracts each of which inclosed three concentric verticils of short-stalked bisporangiate sporangiophores. A third type, *S. fertile*, had peltate bisporangiate sporangiophores, but was unique in that both the dorsal and ventral lobes were fertile; i. e., the sterile bracts or morphologically dorsal foliar lobes were replaced by sporangia bearing fertile lobes. A fourth type, *S. majus*, had lax cones made up of repeatedly forked bracts each with four sessile or very short stalked sporangia on their upper (morphologically ventral) surface. A fifth type, *S. trichomatosum*, had a single sporangium near the axis on each bract. In a sixth form, *S. marginatum*, the sporangiophores were borne on the axis instead of on the bracts. A seventh and remarkably complicated type known as *Cheirostrobus* is often made the type of a distinct family, the *Cheirostrobaceae*. It is unfortunately known only from a few petrified cones from the base of the Lower Carboniferous of Scotland. These cones were large, 3 to 4 centimeters in diameter and about 10 centimeters long, and consisted of closely packed verticils of compound sporophylls, each of which consisted of three upper (ventral) fertile lobes and three lower

(dorsal) sterile lobes. Each of the fertile lobes or sporangiophores bore four radially elongated homosporous sporangia.

This brief sketch indicates that the Sphenophyllae as we know them represent a diversified and ancient stock clearly related to, but more primitive than the Calamariae. Their relation to the Lepidophyta was more remote, the latter showing but slight evidence of a megaphyllous ancestry or of sporangiophores, the sporangia being borne directly upon the sporophylls or in their axils. There is considerable homology in the stelar anatomy of the two groups and it seems probable, especially with the variations of strobilar morphology among the Sphenophyllae in mind, that morphologists have magnified the importance of these features as contrasted with those in the Lepidophyta. At any rate, the view is advocated here that both the Arthrophyta and Lepidophyta go back to a very ancient common ancestral stock from which also the Sphenophyllales as we know them were descended.

The second class of arthrophytes—the Calamariae, include three orders—namely, the ancient Pseudoborniales, the Calamariales, comprising the large and diversified calamites of the Paleozoic, and the Equisetales, sparingly represented in the Paleozoic, somewhat more abundant in the Mesozoic, and represented in the existing floras as the sole survivors of the whole arthro-

phyte phylum. The Pseudoborniales are imperfectly known, being based upon impression from the Upper Devonian of Bear Island described in the first instance by Heer as *Calamites radiatus*. The main stems were of considerable size, reaching 10 centimeters in diameter, with nonalternating ribs. The leaves, of relatively large size, were in whorls (probably in fours), short-stalked, and palmately and repeatedly dichotomous. The fructifications were long lax cones with whorled sporophylls resembling reduced vegetative leaves, and the sporophylls bore sporangia on their lower surfaces. These important plants, unfortunately too little known, show decisive evidence of a megaphyllous ancestry. Scott has suggested a comparison with *Cheirostrobus* based upon the complexity of the latter and the compound leaves of *Pseudobornia*. Irrespective of this somewhat remote



FIG. 7.—Leaf of *Pseudobornia ursina* Nathorst from the Devonian of Bear Island.

comparison, the Pseudoborniales in habit and structure, in so far as these are known, were evidently allied to the Protocalamariaceae (formerly referred to the genus *Bornia*) and help to bridge the gap between the Calamariae and the Sphenophyllae.

The Protocalamariaceae, which are common in the Devonian and Lower Carboniferous, occurring as late as the Pottsville formation of the Upper Carboniferous, are generally referred to the genus *Archaeocalamites*, although the terms *Bornia*, *Protocalamites*, *Asterocalamites*, etc., have also been used for them. The stems, most frequently preserved as casts, were often of considerable size; they show low, flat, nonalternating ribs separated by shallow furrows; the internodes were of unequal lengths and the lateral branches were irregularly grouped at some and not at other nodes. The leaves were free and in whorls; they were narrow and lanceolate or repeatedly dichotomous with linear or filiform segments. According to Renault the pith cavity was large and surrounded by a woody cylinder of wedge-shaped groups of tracheids with secondary rays. A carinal canal was located at the apex of each primary group and the primary rays were shut off by interfascicular wood early in the course of secondary thickening. In a stem from the basal Carboniferous of Scotland a considerable arc of centripetal wood was formed inside the carinal canal—a primitive feature, otherwise unknown in the Calamariales except in the roots.

Such incomplete accounts as are available indicate that the cones may have exhibited variations comparable with those among the Sphenophyllae, although much less is known regarding the former. In the cones described by Renault there were no sterile bracts and each sporangiophore bore four sporangia, while in other cones (*Pothocites*) sterile bracts appear to have been more or less developed. The leaves suggest the Pseudoborniales and some of the Sphenophyllae; the stele was like that of a calamite, while the absence of sterile bracts in some of the cones suggests the Equisetales. There can be no doubt but that the Protocalamariaceae represent a more synthetic group than the Calamariaceae, although probably ancestral to them and to the Equisetales also.

The family Calamariaceae was one of the dominant groups of plants during the Carboniferous and various of its members often reached a large size with a corresponding complexity of structure. Pith casts upward of 30 feet in length and 12 inches in diameter have been recorded, and Grand'Eury estimated the height of some of the French calamites as about 100 feet and with a trunk diameter of several feet. Secondary wood was usually formed, although the common mode of preservation was as casts of the fistular medullary cavity. The vascular bundles usually alternated at the nodes. The foliage of the Carboniferous forms comprised two main types—namely, *Asterophyl-*

lites—in which the leaves were linear acuminate, univeined, and generally free from the others of the nodal whorl. This type of foliage is very common and it would seem that the bulk of the calamites had foliage of this sort. The second type of foliage known as *Annularia* was like the former in habit, but the leaves were relatively broader, of unequal lengths in each whorl, and appear to have been slightly connate proximad. It is impossible to correlate foliar branches with stem casts, cones, and structural material, so that while all of the parts

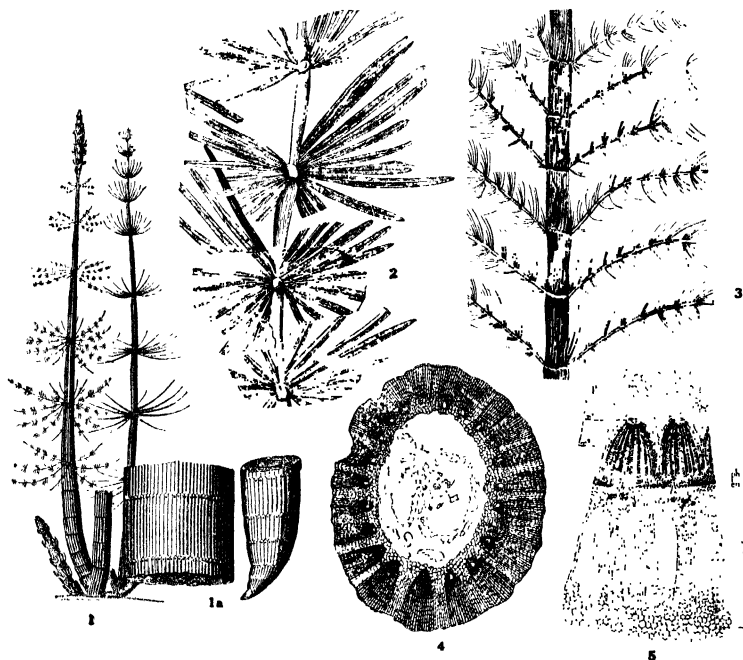


FIG. 8.—Views of Calamite foliage and stems.

1. Restoration of Calamites (after Zittel).

1a. Medullary cast of a Calamite stem and branch.

2. *Annularia longifolia* Brongn., from Carboniferous of Bohemia (after Feistmantel).

3. *Asterophyllites equisetiformis* (Brongn.) from Carboniferous of Bohemia (after Feistmantel).

4. Transverse section of stem, *Calamodendron*, from the English Carboniferous (after Schenk).

5. Transverse section of root, *Astromyelon*, from the French Permian (after Renault): p, pith; x1, primary centripetal xylem; x2, secondary xylem; ph, phloem; en, endodermis; l, lacunae in cortex; w, walls of lacunae; c, outer cortex.

of the calamites are well known in different examples, it is necessary to maintain these different categories for the different classes of remains. The foliage varied considerably not only from species to species, but on the same plant, and while the two foregoing types constitute useful form genera, it is not always possible to differentiate sharply between them. The genus *Nematophyllum* of the West Virginia Permian shows greatly elongated linear leaves, from 10 to 20 in a whorl, and suggests a modification in the direction of the Triassic *Schizoneura* and *Neocalamites*.

Schizoneura, a type of the Permian and Triassic, had leaves which were at first united in a sheath or in several broad sheath segments that subsequently split into a varying number of multiple-veined divisions. Neocalamites of the Triassic had free univeined leaves greatly resembling those of Annularia in some of the late Triassic species. Phyllothea, a Permian and early Mesozoic type, had acicular, slightly connate, univeined leaves and the sporangia were borne by peltate sporangiophores alternating with whorls of sterile bracts. Nematophyllum, Schizoneura, Neocalamites, and Phyllothea are all based upon impressions, so that a knowledge of the structure or the details of organization of their fructifications is unfortunately wanting. Structurally calamite leaves show a central trace surrounded by a broad zone of mesophyll.

Several generic types of calamites have been based upon stem anatomy. These include Arthropitys (the *Calamites vera* of British botanists) in which the pith was large and hollow except peripherally, with persistent diaphragms at the nodes. Surrounding the pith was a ring of collateral vascular bundles, the protoxylem in all but the youngest stems being disorganized to form longitudinal passages known as carinal canals. The wood was entirely centrifugal in its development. Secondary wood formation started early and consisted of scalariform or radially pitted tracheids and variable rays which continued with undiminished width through the vascular cylinder or tapered outward or were abruptly shut off by interfascicular wood. The cortex consisted of an inner thin-walled zone of cells and an outer denser zone in which there was a very great development of periderm. The courses of the leaf traces was somewhat varied and more complicated than in the Equisetales, otherwise Arthropitys was much like an Equisetum with the addition of secondary thickening. A second type, known as Arthrodendron and confined to the British Coal Measures, had a thin zone of wood, in which the primary bundles were widely separated by the principal rays which consisted of elongated fibrous elements (prosenchyma), within which there were secondary rays of parenchyma like those of the secondary wood. In the latter the tracheids are reticulate, and the infranodal canals very large. A third type, Calamodendron, of the European Upper Carboniferous and Permian, had radial bands of prosenchyma containing secondary rays between the normal rays and the radial bands of secondary wood. The roots of calamites preserved as impressions, which are of widespread occurrence, are known as Pinnularia. Structural root material, known as Astromylon, shows a usually persistent pith surrounded by a ring of centripetally developed primary wood alternating with groups of primary phloem. The zone of secondary wood was wide; the endodermis appears to have been double; and the cortex was very thick with large lacunar intercellular spaces, denoting a swampy or aquatic habitat.

Great numbers of a variety of calamite cones are known from impressions, as the large cones of *Macrostachya*, the more openly constructed cones of *Huttonia*, and the curious cones of *Cingularia*. The two types, *Calamostachya* (*Volkmannia*) and *Palaeostachya*, are also represented by a considerable amount of petrified material with the structure preserved. In *Calamostachya* the whorls of peltate sporangiophores, each bearing four pendent sporangia, alternate equidistantly with usually twice as numerous sterile bracts, which are connate or free basally and whose upturned imbricated and strengthened tips effectually protected the inclosed sporangia. The latter are elongated sacs with their walls but one cell in thickness, but stiffened by ridges, and containing numerous tetrads of spores. In some species the spores appear to be all of one kind (homosporous), although they are somewhat unequally developed in *C. binneyana*. Other species (e. g., *C. casheana*) were heterosporous, although both microspores and megaspores were borne in the same region of the cone. Other species (*C. grandewryi*) had radial sterile plates connecting the sporangiophores with the adjacent bracts, thus inclosing each group of four sporangia in a radial compartment. Although the sporangiophores were borne on the cone axis midway between the whorls of sterile bracts, their supply bundles have a common origin, forking at the nodes, and that of the sporangiophore passing upward more or less across the interval of the internode and then bending downward and entering the sporangiophore, thus indicating that, although widely removed from the bracts, the sporangiophores were morphologically their ventral appendages as in *Sphenophyllum*. *Calamostachya* is usually but not invariably associated with the *Asterophyllites* type of foliage.

Petrified material of *Palaeostachya* is less common than that of *Calamostachya*. The former cones differ in having the sporangiophores inserted in the axils of the bracts and inclined upward—features usually discernible in impression material. The bracts were imbricated and more or less connate proximad. The sporangiophores, half as numerous as the bracts, bore four pendent sporangia from their peltate tips. Some cones appear to have been homosporous and other heterosporous. It has been commonly assumed from the axillary position of the sporangiophores that *Palaeostachya* was more primitive than *Calamostachya*, but in one species at least of the former the supply bundles pursue an at first ascending and subsequently descending course similar to what obtains in *Calamostachya*. Some of the *Palaeostachya* cones are of large size and they are usually associated with the *Annularia* type of foliage.

Macrostachya is the name applied to exceedingly large cones of calamites preserved as impressions. They show considerable variation and are said to have been heterosporous. *Huttonia* includes

large cones somewhat resembling those of *Macrostachya* but more open and characterized by a disk-like protective flange pendent from the bract whorls. *Cingularia* comprises long and lax cones with widely spaced whorls of coherent bracts at right angles to the axis, subtended by whorls of nonalternating sporangiophores, equal in number to the bracts. The sporangiophores were ligulate and divided distad and each division bore two large pendent sporangia.

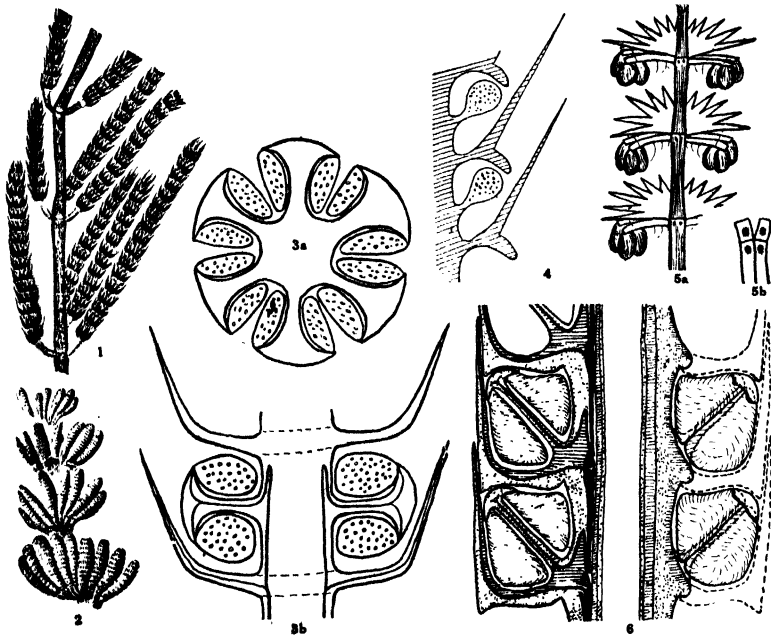


FIG. 9.—Types of Calamite fructifications.

1. *Palaeostachya elongata* Presl (after Schenk).
2. *Calamostachya jugleriana* Schimper (after Goeppert).
- 3a. Transverse section of cone of *Calamostachya* passing through a whorl of sporangiophores.
- 3b. Median vertical section of *Calamostachya*.
4. Diagrammatical median section of *Huttonia*.
- 5a. Part of cone of *Cingularia typica* (after Weiss).
- 5b. Two sporangiophores of preceding seen from below.
6. *Palaeostachya vera*, Diagrammatical median vertical section (after Hickling):
 vascular tissue black.
 scleritized parenchyma lined.
 soft parenchyma dotted.

On the left the section passes through a bundle and on the right between bundles.

The final order of the Calamariae, the Equisetales, consists of the single family, Equisetaceae, and comprises at the present time the single genus, *Equisetum*, with 25 to 30 rather uniform, widely distributed, mostly small and chiefly temperate species of scouring rushes or mare's tails. The cones are terminal on fertile shoots or on branches from the vegetative shoots, and entirely lack sterile bracts. They consist of peltate sporangiophores carrying from 5

to 10 homosporous sporangia. The rhizomes or underground stems of the species with annual shoots commonly form tubers, and these often occur abundantly as fossils, as in the Lower Cretaceous of Maryland. The Equisetales were represented by a number of small and imperfectly known Paleozoic species referred to the genus *Equisetites*. During the Triassic they were represented throughout the world by stem casts, often of large size, with alternating ribbed

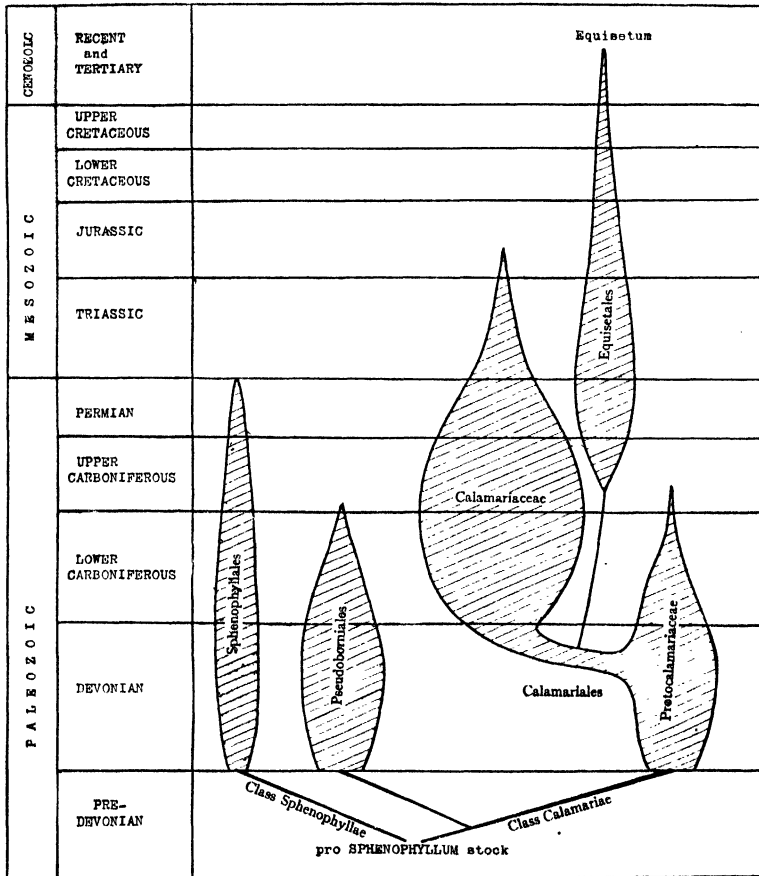


FIG. 10.—Diagram showing the geologic history and phylogeny of the Arthrophyta.

stems and the leaves united into sheaths at the nodes. They continued as not uncommon types throughout the Jurassic in all parts of the world, decreasing gradually in size and abundance during the later Mesozoic until their status and size in the Cenozoic floras was much as in the existing flora.

The generalized geological ranges of the various arthrophyte groups as well as their relative importance at different periods and their filiation are shown in the accompanying diagram.

PHYLUM LEPIDOPHYTA.

The *Lepidophyta* occupy in some respects an isolated position among vascular plants, although there are not wanting students who connect them with the *Hepaticae* or the *Sphenophyllales* on the one hand, and with the seed-bearing plants on the other. The phylum includes the tiny existing quillworts and herbaceous clubmosses, as well as the often gigantic *Lepidodendrales*, which occupied such a prominent position in Paleozoic floras.

Features which serve to unite the somewhat diverse members of this phylum are the small simple leaves, which are spirally arranged, and not verticillate, as in the *Arthrophyta*. All the known *Lepidophytes* are microphyllous, the only suggestion of a departure from a simple type of leaf being the double leaf trace in the Paleozoic *Sigillariopsis*. A second consistent feature is the presence of branch gaps and the absence of leaf gaps in the vascular cylinder, which is thus cladosiphonic, with an exarch protostele. A third feature is the apparently simple relation between the sporangium and the sporophyll, which can be interpreted as due to progressive sterilization according to Bower's well-known theory, or may be explained as a reduction from the same or similar sporangiophoric ancestors that give rise to the *Arthrophyte* phylum.

The *Lepidophyta* are prevailingly strobiloid and are known from the Devonian to the present. Some are homosporous, other heterosporous, while still other Paleozoic forms had practically crossed the boundary that separates spore production from seed formation. Further details are best given in the discussion of the various types which follow. The geologic history and mutual relationships of the different members of the phylum are shown in the accompanying diagram and in the light of present knowledge may be expressed in tabular form in the following manner:

Order *Lypidodendrales*: Family *Bothrodendraceae*, Family *Lepidodendraceae*, Family *Sigillariaceae*.

Order *Lycopodiales*: Family *Lycopodiaceae*, Family *Selaginellaceae*.

Order *Isoetales*: Family *Isoetaceae*.

Order *Psilotales*: Family *Psilotaceae*.

It will make for clearness to consider the existing forms and their fossil representatives before describing the wholly extinct *Lepidodendrales*. The *Lycopodiales* comprise the two families *Lycopodiaceae* and *Selaginellaceae*. The former includes two genera, *Lycopodium* and *Phylloglossum*. *Lycopodium* has about 100 widely distributed existing species of mostly perennial erect or trailing herbaceous forms of shaded woods, marshes, etc., some tropical species epiphytes. But one kind of spores are formed and the

sporangia are borne on or in the axils of scarcely modified foliage leaves more or less distinctly aggregated into strobili.

Fossil species of *Lycopodium* or *Lycopodites*, which is often preferred as a less definite name, are especially liable to be confused with the foliage of some of the *Lepidodendrales* or *Coniferophytes*, unless represented by fructifications. Among the rather numerous forms referred to *Lycopodites* and scarcely different from the exist-

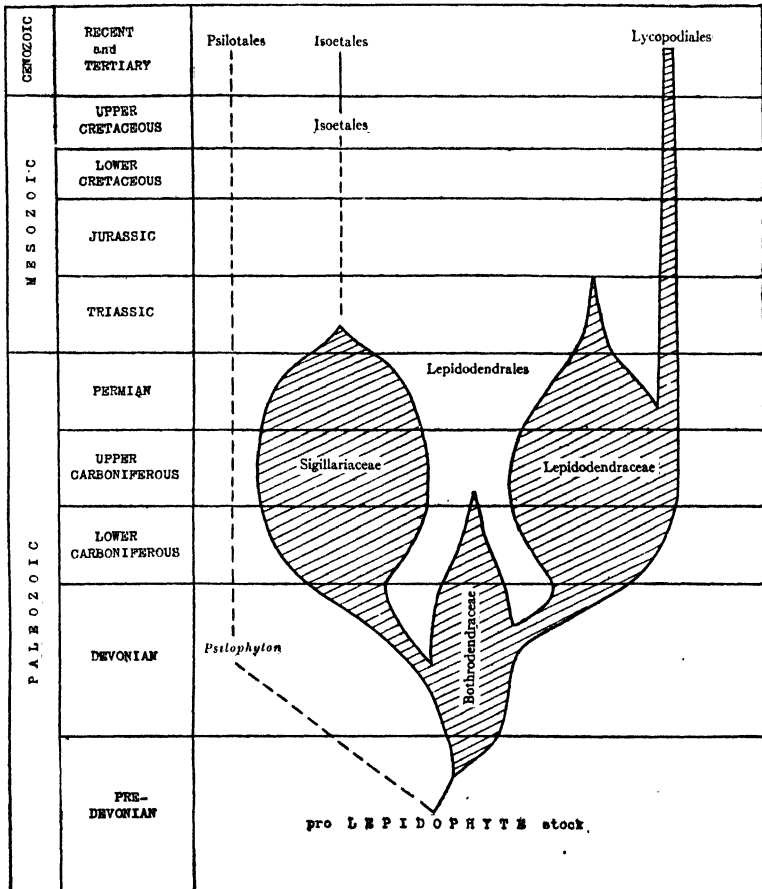


FIG. 11.—Diagram showing the geologic history and phylogeny of the Lepidophyta.

ing forms may be mentioned *L. Stockii*, Kidston from the Lower Carboniferous, *L. Gutbieri*, Göpp., and *L. Reidii* Penhallow from the Devonian; *L. macrophyllus* Goldenberg; and *L. Zeilleri*, Halle from the Upper Carboniferous; *L. lanceolatus* (Brodie) and *L. Scanicus* Nath. from the Upper Triassic; *L. falcatus*, L. and H., *L. tenerrimus* Heer, *L. victorise* Seward from the Jurassic; and *L. cretaceum* Berry from the Upper Cretaceous. While *Lycopodium*-

like forms were never apparently very different from what they are at present, they represent a very ancient line and were represented as a minor element associated with the diversified arboreal Lepidophyte flora of the Paleozoic.

The genus *Phylloglossum* consists of a single species of Australia and New Zealand with a reduced tuberous stem and relatively large leaves, closely related to *Lycopodium*, although by some students considered the most primitive lycopod.

The second family, the Selaginellaceae, consists of the single genus *Selaginella*, with about 500 species of mostly mesophytic small plants not differing greatly from the Lycopodiaceae, except that after the mother cell stage the spores differentiate into microspores and megaspores. The foliage is usually dimorphic and both foliage leaves and sporophylls have a ligule. The cones are not highly differentiated from the vegetative leaves. Sometimes but one megaspore is developed in a sporangium and fertilization may take place before shedding, thus illustrating steps in the acquisition of the seed habit. Fossil species of *Selaginella*, unless they are fruiting, are not certainly distinguishable from Lycopodites, nevertheless several undoubted species have been recorded from the Carboniferous (*Selaginellites Suissei* Zeiller, *S. primaevus* (Goldenberg) *S. elongatus* (Gold), *S. scilliatum* (Kidst). Less authentic species are recorded from Mesozoic and Cenozoic deposits of widely scattered regions.

The second order, the Isoetales, consists of the single genus *Isoetes*, with about 60 existing aquatic or palustrine species, with a reduced tuberous stem and a crowded rosette of grasslike ligulate leaves which are relatively larger than in the majority of Lepidophytes. Microspores and megaspores are produced, both characterized by their large size and by the formation of trabeculae or strands of sterile tissue often completely dividing the sporangial cavity. Secondary thickening occurs and morphological resemblances to the ancient *Sigillarias* and modern Monocotyledons have frequently been insisted upon, although without logical basis. Fossil forms are exceedingly rare. Saprota recorded a form from the Lower Cretaceous (Barremian) of Portugal (*Isoetites Choffati*). Aside from untrustworthy records *Isoetes* occurs in the Oligocene of France and the Miocene of Switzerland.

The third order, the Psilotales, is one which has excited a great deal of discussion. It comprises the two genera *Psilotum* and *Tmesipteris*; the former with two species of both Tropics and the latter with a single Australasian species, although more are frequently recognized. Both genera are considered to be more or less saprophytic. The sporophylls of *Psilotum* consist of a much shortened bifurcated axis bearing adaxially a bilocular or trilocular synangium producing but one kind of spores. In *Tmesipteris* the

sporophylls, alternating with foliage leaves, or more or less zonal in their development, consist of a short axis terminating in a pair of lanceolate lobes and bearing adaxially an elongated bilocular slightly stalked synangium, and producing but one kind of spores. Both genera show a decided tendency toward repeated branching of the sporophylls, a feature much emphasized by Thomas, Scott, and Bower, but believed by the writer to be without significance. Whether the sporophyll be regarded as morphologically a branch or a leaf is disputed.

Those who accept the latter view regard the Psilotales as sporangiophoric and closely related to the Sphenophyllales. Others consider that the necessities of nutrition of large sporangia with many spores resulted in the formation of sterile plates, such as occur in *Isoetes* and in the sporangia of some of the *Lepidodendrales*, and regard the bi- or trilocular sporangia of the Psilotales as septate unilocular sporangia. The view that these masses of sterile tissue may represent vestiges derived from sporangiophoric ancestry has not been sufficiently emphasized and will be referred to in a subsequent paragraph. Meanwhile, it may be said that the action of Scott and others in separating the Psilotales from the *Lepidophytes* and grouping them with the *Arthrophytes* is greatly to be deprecated. The fossil history of the Psilotales is unknown. Various fragmentary specimens described as *Psilotites* are without value. Among the doubtful forms that have been related to the Psilotales are the Devonian genera *Psilophyton*, *Dimeripteris* and *Pseudosporochus*, and the Permian genus *Gomphostrobus*.

The order *Lepidodendrales* merits a more extended consideration than has been accorded the preceding three orders. It consists of three well-marked families very prominent in Paleozoic floras, the *Bothrodendraceae*, *Lepidodendraceae*, and *Sigillariaceae*, to which should possibly be added the *Pleuromoiaceae* for the reception of Triassic *Sigillaria*-like plants. Although herbaceous remains are known, the vast majority of the *Lepidodendrales* were arborescent and some of them reached a height of 100 feet or more. The most ancient of these families, the *Bothrodendraceae*, unites in many respects the features that later characterized the *Sigillariaceae* on the one hand and the *Lepidodendraceae* on the other. The *Bothrodendraceae* are especially characteristic of the Devonian and Lower Carboniferous. They were cosmopolitan and their abundance may be indicated by the fact that the so-called paper coal of Russia consists almost entirely of their flattened cuticles. A number of generic types have been recognized, although our information regarding them is vague in a good many particulars.

Bothrodendron, or *Cyclostigma* as it has frequently been called, is not very different in the appearance of impressions of the stem from some species of *Sigillaria*. The stems were dichotomously

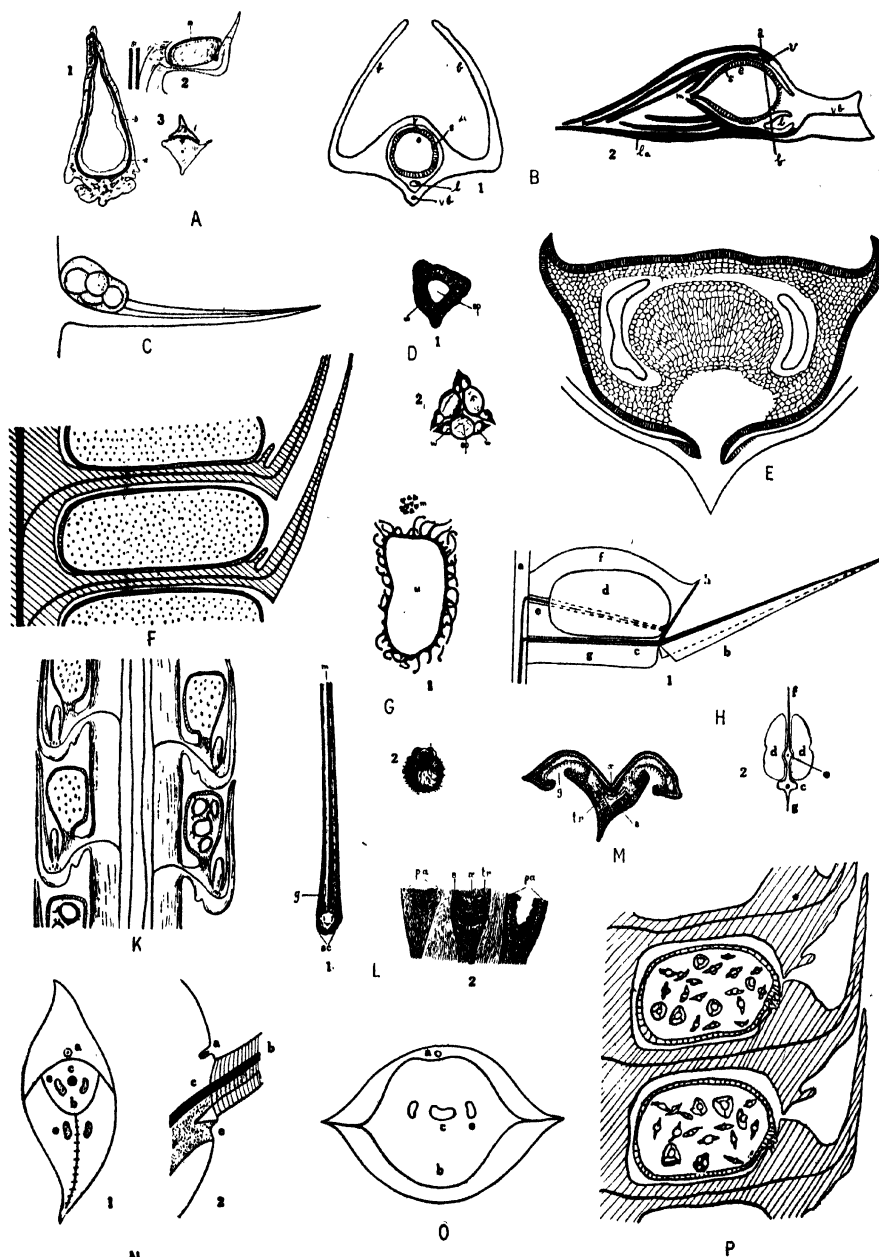


FIG. 12.—Fructifications, leaves and bolsters of various fossil *Lepidophytes*.

(Explanation for figure on next page.)

branched. Bolsters are usually wanting and the leaf scars are remote, small and circular or rhomboidal, they show a central leaf trace scar and two lateral parichnos scars; immediately above and close to the leaf scar is a small ligular pit. The leaves were small, linear lanceolate, univeined, and more or less persistent. In one species (*B. punctatum*) the self-pruning of branches resulted in the large scarred impressions known as Ulodendron. The term Rhytidodendron has been used for some species and recently the genus Porodendron has been proposed for certain forms from the Lower Carboniferous of Russia and Spitzbergen that were formerly referred to Bothrodendron. Anatomically, the stems show either a small pith or a solid core of wood with external protoxylem. The secondary zone of wood was thin and the cortex was less differentiated than in the Lepidodendrales.

A cone, *Lepidostrobus Olryi* Zeiller, which is considered to have belonged to *Bothrodendron minutifolium* is of the usual Lepidostrobus type with elongated sporangia. A small cone with a histology that suggests its having been borne by *Bothrodendron mundum* lacks the radially elongated sporangia and instead has them extended upward inside the sharply flexed bracts and is conspicuously ligulate. It bore microsporangia in the distal and megasporangia in the proximal region. Another type of cone, *Lepidostrobus Zeilleri*,

EXPLANATION FOR FIG. 12.

- A. Lepidocarpon lomaxi Scott:
 1. tangential section (after Scott).
 2. diagram of sporophyll; m, micropyle, St. stele (after Seward).
 3. tangential section near distal end of immature sporophyll; l, ligule (after Scott).
- B. *Midasmia membranacea* (modified from Scott):
 1. tangential section 1a and b, lamina of bract forming wings; v, velum or integument with its processes; c, sporangium.
 2. radial median section m, micropyle, l, ligule.
- C. *Pinakodendron ohmanni*, megasporangiate sporophyll (after Kidston).
- D. *Spencerites insignis* (after Williamson):
 1. spore showing wing in surface view, sp. cavity, w, wings.
 2. tetrad in section showing 3 spores.
- E. *Mazocarpon*. Diagrammatical transverse section of megasporophyll II (after Benson).
- F. *Lepidostrobus veltheimianus*, median vertical section.
- G. Same showing megaspore, M, and microspore, m, in section (after Kidston):
 2. single megaspore in surface view.
- H. *Cantheliophorus*, 1, radial and 2, transverse section (after Bassler):
 a, axis; b, blade; c, pedicle; d, sporangium; e, bract; f, crest; g, keel; h, guard.
- K. *Bothrostrobus*, median vertical section (after Watson).
- L. *Sigillaria spinulosa* (after Renault):
 1. leaf from below showing furrows and scar.
 2. tangential section of outer cortex showing leaf trace and parachnoi:
 pa, parachnoi; x, xylem, primary above, secondary below; tr, phloem; s, sheath of bundle.
- M. *Sigillaria latifolia*, transverse section of leaf (after Renault):
 x, xylem; s, schlerenchyma; tr, transfusion tissue; g, stomatiferous furrows.
- N. *Lepidodendron* bolster. 1, surface view; and 2, in median radial section:
 a, ligule; b, leaf and leaf scar; c, leaf trace; e, parachnoi.
- O. *Sigillaria* bolster in surface view:
 a, ligule; b, leaf scar; c, leaf trace; e, parachnoi.
- P. *Spencerites insignis*, Diagrammatical radial section showing two sporophylls with megasporangia (after Berridge).

which may belong to *Bothrodendron tenerrimum*, appears to lack sterile bracts.

Another genus, distinguished from *Bothrodendron* by the surface ornamentation of fine raised lines between the remote leaf scars, is *Pinakodendron*. Several species have been described, and in one, *P. Ohmanni*, the megasporangia were attached to the basal adaxial faces of the sporophylls of the same size and form as the foliage leaves, and borne on certain parts of the branches, but not terminal as were most *Lepidophyte* cones.

Other genera of somewhat doubtful affinity are *Leptophloeum* in which the leaf scars are more crowded, and *Omphalophloios* in which rhomboidal bolsters were developed. *Leptophloeum* occurs in the Devonian or Lower Carboniferous of North America, Europe, Asia, and Spitzbergen, while *Omphalophloios* is found in both America and Europe.

Other related forms are referred to the genus *Archaeosigillarea* or *Protolepidodendron*. The most remarkable of these is a large trunk from the Middle Devonian of New York shown in figure 28. The actual specimen, preserved in a fine-grained blue shale, was 5 meters in length and 38.5 centimeters in diameter at the swollen butt, and 12 centimeters in diameter at the distal end. In appearance the slender arching bifurcating branches with the subulate falcate persistent leaves gave it a weird aspect. The swollen base and tapering stem indicate some secondary thickening. At the base, rootlets similar to those of *Stigmaria* are preserved. The leaf cushions at the base are distant and irregular. Higher up they are in vertical rows on ribs separated by angular furrows as in *Sigillaria*, while still higher up they pass gradually into typical rhomboidal spirally arranged *Lepidodendron* bolsters. The leaf scars are in the upper part of the bolsters, obovate in form or slightly cordate above, and show a subcentral leaf trace scar flanked by crescentic parachnoi, with a well-marked ligular pit immediately above the margin. *Protolepidodendron* thus unites the features of *Lepidodendron* and *Sigillaria* in one synthetic type and it seems probable that the majority of Devonian forms that have been referred to those two genera really represent *Protolepidodendron*. Other species have been recorded from various European Devonian localities.

In the family *Lepidodendraceae*, the majority of the species were tall trees reaching in some cases a height of 40 meters, with a straight shaft unbranched for a long distance above the ground, with a dense crown of dichotomously forked branches covered with crowded masses of long narrow simple leaves spirally arranged, and with large terminal cones. The leaves were ultimately shed from the older portions of the trunk and the geometrically sculptured stems are among the commonest of Carboniferous fossils affording the

characters by which several hundred species have been distinguished and utilized for stratigraphic purposes. The perfection of preservation of these trunk surfaces indicates an absence from the Carboniferous forests of the numerous parasitic and epiphytic forms which crowd tree trunks in the present day tropical forest.

The essential features of the surface markings are of considerable importance. The leaf cushions or bolsters were crowded in spiral arrangement with angles above and below, and rounded sides (rhombic), always longer than broad and truncated above the middle, where the abscission of the leaf occurred. The leaf scar is subcircular and shows three scars—a central one representing the leaf trace and laterals on each side known as parachnoi. Just above the leaf scar is a small triangular print left by the ligule, while below the leaf scar there are frequently two rounded prints or depressions on either side of the keel which, like the parachnoi, are tracts of thin-walled tissue which functioned as aerating tissue. Other markings of an ornamental character are frequently present on the bolsters. With the decay of the cortex the characteristic *Lepidodendron* features gradually become obliterated. If merely the epidermis is gone the resulting features are those of *Bergeria*, once thought to represent an independent genus. If decay has removed part of the cortex the forms are known as *Aspidaria*, and if all of the outer cortex is gone showing the imbricated leaf traces it is known as *Knorria*.

Anatomically the stem is monostelic with centripetal primary wood, which may extend to the center or inclose a pith. There is usually a considerable development of centrifugal secondary wood consisting of scaliform tracheids and medullary rays. Primary phloem has been recognized but there is some doubt regarding the presence of secondary phloem or of any persistent cambium. In forms that have not been demonstrated to have formed secondary wood, secondary thickening takes place in the outer cortex through the development of a periderm.

Leaf traces, collateral in structure, pass off from the stele without leaving any gaps and pass obliquely through the cortex to the leaves, each leaf receiving a single bundle. The cortex is of great thickness and variable according to age and species. Usually there is an inner parenchymatous zone poorly preserved. The outer cortex consists of thicker walled elements, usually with an enormous development of phelloderm, which served for the lack of mechanical tissue in the vascular cylinder.

The leaves had a single central vascular bundle surrounded by a sheath of transfusion tissue and the stomata are commonly restricted to two deep grooves on the lower surface. What corresponds to the roots in higher plants are peculiar organs known as *Stigmaria*, which as casts or impressions are among the commonest coal measure

fossils, particularly in the underclays beneath the coal seams. In complete specimens the main axis is seen to divide into four main forks which run horizontally and branch dichotomously. The surface is smooth or irregular, wrinkled, and covered with well-spaced umbilicate scars from which, in well-preserved material, cylindrical radiating rootlets are seen to diverge. These are slightly constricted at the base and lack root hairs. These are so common that the underclays are often called *Stigmaria* clays, and they are the pest of students of petrified material, since they are found penetrating the tissue of other plants that formed the substratum in the Carboniferous swamps. The main axis consists of a central pith, a ring of centrifugal wood accompanied by phloem and surrounded by a cortex with abundant periderm. Sometimes no distinction between primary and secondary wood is observable, while in other specimens centripetal primary wood is present. The rootlets show a different anatomical arrangement, each containing a monarch stele, with radial vascular strands connecting the protoxylem with groups of cortical tracheids. They arise from the inner margin of the primary wood, although the outer cortex is continuous with that of the main axis.

Stigmaria have frequently been found attached to both *Lepidodendron* and *Sigillaria* trunks. There has been much discussion regarding the morphological nature of *Stigmaria*, since they do not conform to the usual morphology of true roots, but whatever their morphological homologies, physiologically they are roots.

The fructifications of the *Lepidodendraceae* have been described under a variety of generic names, the most common being *Lepidostrobus*. *Lepidostrobus* had an axis similar anatomically to a vegetative twig and bore numerous spirally arranged sporophylls, each bearing a single very large radially elongated sporangium on its adaxial surface. The sporophyll had an upturned blade and these formed an imbricated protective surface for the cone. Between the sporangium and the blade a ligule was present. It seems probable that the *Lepidodendrons* were always heterosporous, the two kinds of spores being produced on different parts of the same cone or upon different cones. The microspores were small, tetrahedral in form, and very plentiful. The megaspores were relatively very large, few in number, tetrahedral in form, with a hairy surface and commonly opening by apical flaps. The prothallus within the megaspore is occasionally preserved and even archegonia have been recognized. In another cone genus, *Spencerites*, the sporangia were united to the sporophyll by a distal neck and the spores were winged. In some *Lepidodendron* cones large masses of sterile tissue are developed within the sporangia suggesting a vestigial sporangiophore, and in *Mazocarpon* the large sausage-shaped megaspores are imbedded in a solid parenchymatous tissue.

Still another type of *Lepidodendron* fructification was *Canthelophorus* in which the sporophylls were commonly deciduous. Each sporophyll bore two large sporangia separated by a median sterile plate interpreted as representing the sporangiophore of the ancestral pro-Sphenophyllum stock.

Ulodendron branches have also been formed on certain species of *Lepidodendron*, and other *Lepidodendron* shoots, known as *Halonias*, are characterized by spirally disposed scars or tubercles thought to indicate the points of attachment of cone peduncles.

The vast majority of stem impressions represent minor variations of the common *Lepidodendron* type. In the genus *Lepidophloios* the bolsters were very prominent and became recumbent in old age, so that the normal leaf scar appears to be at the base. The *Halonias* branches with their spirally stalked deciduous cones appertains particularly to *Lepidophloios*, which, anatomically, was exactly like *Lepidodendron*.

The *Sigillariaceae* are much like the *Lepidodendrons* in essential features, but differed considerably in habit. They attained their maximum development in the Upper Carboniferous and gradually waned during the Permian, although they appear to have survived into the Lower Triassic. The trunks were generally massive and for the most part unbranched, giving them a peculiar appearance and at one time suggesting a relationship with the cycadophytes, since discredited.

Some specimens 6 feet in diameter at the base had tapered to 1 foot in diameter 18 feet above the base, while a French specimen was found preserved for a length of 71 feet, which was 2 feet in diameter at one end and 1 foot 8 inches at the other. The leaves were persistent toward the top of the stem and in some cases were very long and grass-like. Stem impressions, which, like those of *Lepidodendron*, are exceedingly common throughout the coal measures, can readily be distinguished by their vertically arranged scars often on prominent ribs, by the slight development of bolsters, and by the scars being wider than high, with the angles at the sides and rounded above and below. Very many species have been described and the variations observed are very useful for stratigraphic purposes, and have resulted in an elaborate analysis of the types of surface ornamentation. These fall naturally into two main groups: The *EuSigillariae* with ribbed stems, and the *SubSigillariae* with smooth stems.

The *Eusigillariae* show broad longitudinal ribs separated by furrows and are segregated into two subordinate groups: i. e., *Favularia*, in which the ribs are separated by zigzag furrows and the scars by transverse furrows; and *Rhytidolepsis*, in which the ribs are separated by straight furrows and are often much broader than the close set or spaced scars. Where the furrows are broad and intercalated,

narrow ribs without leaf scars are developed. The forms are sometimes set apart under the name *Polleriana*, and when transverse furrows appear, the forms are grouped under the name *Tasselata*.

The various stages of preservation yield characteristic surface features thought to indicate distinct genera by the older students but useful now as descriptive terms. Thus when partially decorticated, the inwardly enlarging strands of *aerochyma* result in vertical rows of pairs of large *mamillae*, and such stems have been called *Syringodendron*. Petrified material of *Sigillaria* is rarely found. The

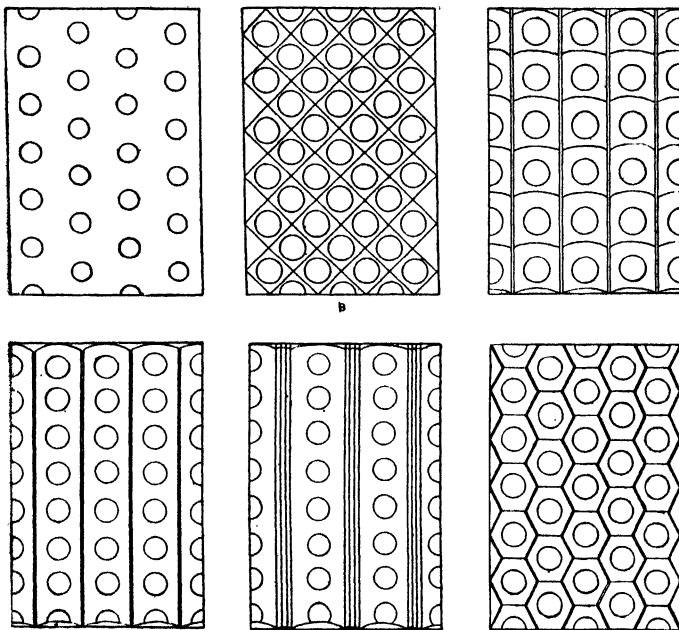


FIG. 13.—Types of *Sigillaria* stem ornamentation (diagrammatic).

A. *Lelodermaria*
B. *Clathraria* } *Subsigillariae*.

C. *Tasselata*
D. *Rhytidolepis*
E. *Polleriana*
F. *Favularia* } *Eusigillariae*.

pith was very large and the vascular cylinder thin and sometimes broken up into separate bundles. Tracheids were reticulate or scalariform, increasing in size centripetally. Secondary wood consists of radically arranged scalariform and pitted tracheids, centrifugal in development with narrow medullary rays. Cortex was thick with an inner soft zone and an outer mechanical zone as in *Lepidodendraceae*. The leaf traces had an inner centripetal primary strand surrounded by a centrifugal secondary zone. The leaves are much like those of *Lepidodendron* with a central concentric vascular strand surrounded by a considerable development of transfusion tissue. In some instances the strand is double. The

cuticle was dense and the stomata were confined to the two furrows on the lower side which were clothed with multicellular hairs.

The cones of *Sigillaria*, usually going by the name of *Sigillarios-trobus*, are common as impressions, but are practically unknown in a petrified condition. They were often very large, being as much as five or six cm. in diameter in *S. nobilis*. They agree in having long peduncles covered with needle-like bracts. The fertile part bears crowded sporophylls of somewhat variable shape with flexed and imbricated distal blades. The sporangia were sometimes attached for nearly their whole length to the adaxial face of the sporophyll, while in other cases they are thought to have been attached distally. Some cones are known to have been heterosporous and this was probably the rule throughout the family. It was formerly thought that both the *Lepidodendraceae* and *Sigillariaceae* became extinct with the Paleozoic, but cones considered to be related to the *Lepidodendraceae* and named *Lycostrobus* are recorded from the Upper Triassic (Rhaetic) of Sweden and certain remains from the Lower Triassic (Bunter) of Europe, known as *Pleuromeia* and sometimes made the type of a separate family, are now believed to represent the *Sigillariaceae*. *Pleuromeia*, which is imperfectly known, is represented by stem casts of simple stems nine to ten cm. in diameter, the surface covered with remote rhomboidal, *Clathraria*-like, leaf scars.

Basally the stem separates into four lobes suggestive of *Stigmaria* or *Isoetes* and covered with rootlet scars like those of *Stigmaria*. Poorly preserved terminal cones of crowded imbricated sporophylls are also known. The form of the stem and the growth separation of the leaf scars indicate secondary thickening; decorticated specimens resemble *Knorria*, and the thin central cylinder all point to a close affinity with the true *Sigillarias*. The cone genus *Poecilostachys*, described by Fliche from the Triassic of France, also indicates a third type of the *Lepidodendrales* which survived the Paleozoic.

There remain for consideration two examples which indicate that some of the *Lepidophytes* had definitely progressed beyond hetros-pory to what amounts to the acquisition of the seed habit. The first of these, unfortunately designated by the preoccupied name of *Lepidocarpon*, comes from the lower Coal Measure of England. In *Lepidocarpon* the cone was of the *Lepidostrobus* type in all its immature details. Only a single megaspore reached maturity in each sporangium, practically filling the whole cavity, and as it matured it was inclosed with a complete investment (integument or velum) which grew up from the adaxial surface of the sporophyll and opened only by a narrow apical micropylar slit. At maturity the whole sporophyll with its integumented megasporangium was shed as a closed seed-like reproductive body.

The second spermatophytic *Lepidophyte* type, known as *Miadesmia* and coming from the Lower Coal Measure of England, was borne on a slender herbaceous form. Each sporophyll bore a ligule like those of the vegetative leaves and had a fringed lamina. The megasporangium was attached to the proximal adaxial face of the sporophyll and developed a single megaspore, which filled its cavity, and was inclosed in an integument arising from the proximal region of the sporophyll, which completely invested the megasporangium, except for a circular micropylar opening at the beak-like distal apex of the sporangium. The micropyle was surrounded by numerous integumental hairs or tentacles, which probably facilitated fertilization. Some megaspores are filled with prothallus. The whole sporophyll was shed at maturity. In some respects *Miadesmia* was more advanced than *Lepidocarpon*, and while neither are morphologically homologous with the seeds of the other spermatophytes, they are physiologically true seeds, which apparently did not evolve further along lines leading to higher plants, as did the seeds of the *Pteridospermatophytes*.

It can not be said that there is any unanimity of opinion regarding the phylogenetic position of the *Lepidophyta*. Some students regard their origin as entirely independent of the *Arthrophyta*, while others regard them as probably distantly related to the *pro-Sphenophyllum* stock that represented the *Arthrophyte* ancestral line. At the other end of the phylum there are students (Seward, Potonié) who consider that the *Araucariales* and perhaps the balance of the *Coniferophytes* diverged from the *Lepidophyte* stock, while others justly doubt that the phylum had any higher issue.

The view advocated here, an opinion frequently advanced, is that the *Lepidophyta* represent a group of forms derived by reduction from more megaphyllous ancestors, and that the prevailing simple relationship between the sporangia and the sporophylls is due to simplification or reduction from sporangiophoric ancestors closely related to the theoretical *pro-Sphenophyllum* type. This view is based in part on a consideration of the paired sporangia of *Cantheliophorus* with their central sporangiophoric plate, on the ventral pad of *Spencerites*, the core of sterile tissue in *Mazocarpon*, the sterile plates in various *Lepidostrobus* sporangia, and the stalked sporangia of the modern *Psilotales*. A consideration of the details of morphology and the fossil record, too extensive a subject for presentation in the present brief review, leads to the conclusion that the *Lepidophytes* are not related to any of the higher seed plants and never gave rise to more highly organized types.

PHYLUM PTERIDOSPERMOPHYTA.

The recognition and partial elucidation of the seed ferns of the Paleozoic is one of the outstanding paleobotanical achievements of the

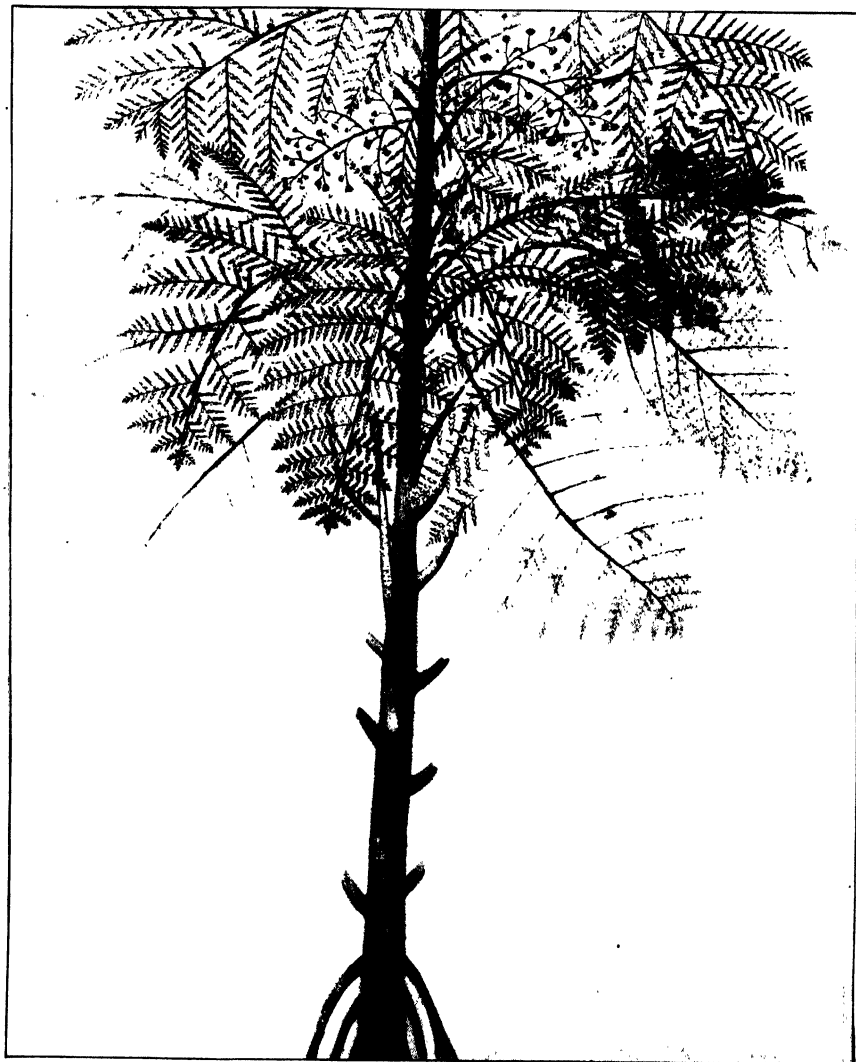


FIG. 14.—RESTORATION OF LYGINOPTERIS, THE BEST KNOWN PALEOZOIC SEED FERN.

last decade. It is needless to dwell on the immense advantages which seed bearing confers on the plants which have acquired this habit. The mere fact that seed plants are the dominant existing plants is sufficient proof of this.

Over a generation ago Stur suggested that the fronds of *Neuropteris*, *Alethopteris*, and other form genera of fern-like fronds exceedingly common in the Paleozoic were probably related to the cycads since they were never found in a fruiting condition like normal ferns. Subsequently the anatomy of certain petrified stems showing a combination of fern and cycad characters led to the proposal of a group, the *Cycadofilicales*, for these intermediate types. Meanwhile, the structure of a considerable number of Paleozoic seeds suggestive of cycads, ginkgos, and gnetales had been described, but beyond correlating some of them with *Cordaitea* little was known of the plants which bore the majority. In 1903 Oliver and Scott succeeded in proving that certain seeds (*Lagenostoma*) were borne on fronds of the *Sphenopteris* type and these in turn were attached to stems known as *Lyginodendron*. This discovery stimulated an interest in the subject and a succession of discoveries followed, so that enough is now known to warrant considering a large number of the supposed Paleozoic ferns as *Pteridosperms* or seed ferns. The manifestly primitive characters show in one feature or another, such as the more or less free nucellus, the complex vascular supply of the seeds, their total lack of an embryo, the fact that both megasporangia and microsporangia were borne upon but slightly modified foliage leaves of decomposed fernlike fronds, and various recondite histological characters, justify regarding the seed ferns as representing a distinct phylum—the *Pteridospermophyta*. They were gymnospermous in habit and some students regard them as a subordinate class of gymnosperms—a taxonomic term that has outlived its usefulness for other than descriptive purposes.

The *Pteridospermophyta* may be tentatively characterized as plants with the habit and, to a large extent, with the anatomical features of ferns, but differing in producing integumented megasporangia or seeds borne on the usually but slightly modified fernlike foliage and never aggregated into true strobili; having secondary thickening in both stems and roots.

From the rapidly increasing contributions to the knowledge of the *Pteridosperms* it will suffice to describe a few of the better known forms. Among these the best known is *Lyginodendron*, or *Lyginopteris* as it is more properly called. *Lyginopteris* represents a group of species with slender, scrambling, mostly unbranched stems of considerable length bearing large forked decomposed fronds upward of a meter in length and long known under the name of *Sphenopteris Höninghausi*, whose persistent petioles (*Rachiopteris*) were almost

as large as the main stem on which they were arranged in a two-fifth spiral. The roots (*Kaloxylon*) were partly adventitious, the stem cortex was fibrous and reticulate and was clothed with spines and capitate glandular hairs. The seeds (*Lagenostoma*) were borne in lobate cupules while the pollen was on the other and more reduced fronds in rosettes of six or seven fusiform bilocular sporangia (*Crossotheca*). The accompanying restoration gives an idea of the habit of *Lyginopteris*, but fails to show the forking of the frond stipes.

The absence of an embryo has led to questioning the use of the term seed for *Lagenostoma* and other Paleozoic forms. They are indubitable seeds, however, and the absence of an embryo may be explained by the resting period having occurred after pollination, while embryo formation was postponed until after the seeds had been shed, and immediately preceded germination.

Lyginopteris was monostelic with a large pith containing sclerotic tissue. Primary wood consisted of from five to nine collateral strands. In all but the most immature stems there is a broad zone of secondary wood of pitted tracheids and medullary rays. The cambium was persistent and is sometimes petrified, as is the phloem. The cortex comprises a thin periderm and an inner, poorly preserved soft cortex and an outer cortex characterized by radial bands of fibrous tissue. Leaf traces are mesarch and double. Anomalous features are the occasional formation of inverted secondary wood by the intrusion of the cambium through a foliar gap.

The seeds, 5 or 6 minims in length, were borne in a lobed cupule and were orthotropous and radially symmetrical, with a single integument confluent with the nucellus except distad. The free part forms a plug and the pollen chamber was hence reduced to a conical slit. The integument was supplied by nine vascular strands which ran to the apex, which formed a fluted dome or radially septate canopy at the apex of the barrel-shaped seed.

The microsporangia were found in connection with vegetative fronds by Kidston. They are of a type known as *Crossotheca* and consisted of a rosette of six or eight bilocular fusiform sporangia. Other types of microsporangia may well have been present in different species of *Lyginopteris*, as, for example, those called *Telangium*, in which the sporangia are concrescent proximad. A second genus of seed ferns which is fairly well known is *Heterangium*, which had long angular slender stems with large and graceful forked (*Sphenopteris elegans* Brongn.) fronds arranged in a three-eighths spiral. While the evidence is less conclusive than in *Lyginopteris* there are good reasons for considering the seeds known as *Sphaerosstoma* as those of *Heterangium*. *Heterangium* had a monostelic stem like *Lyginopteris*, but the pith was replaced by mesarch primary wood, as in some recent ferns. The secondary zone was thin. The

seeds (*Sphaerostoma*) are small with an inner integument and an outer integument or cupule, both with an elaborate vascular supply. The free apical part of the nucellus is a relatively flat plinth surmounted by a central dome or lagenostome, which is surrounded by an annular pollen chamber. The free apical part of the integument formed a frill or canopy with eight radial crests around the micro-pyle. *Heterangium* has a greater range than *Lyginopteris*, being found from the Lower Carboniferous to the Permian. Seeds of *Lyginopteris* or *Heterangium* are found in the French Coal Measures associated with the frond genera *Sphenopteris elegans*, *S. dissecta*, and *S. obtusiloba*.

A second family type to which at least four genera are referable is the *Medullosaceae*. These are characterized by the enormous development of the fronds of the *Neuropteris* and *Alethopteris* type with petioles several centimeters in diameter. This enormous display of foliage is doubtless to be correlated with the peculiarities in the anatomy of the stems. The most primitive known genus, one indicating the point of departure of the other and more specialized members of the family is *Sutcliffia* of the English Lower Coal Measures.

Sutcliffia had a large pithless central stele of centripetally formed wood from which meristeles branch and divide and fuse irregularly and eventually give rise to leaf traces, a large number of which enter each petiole, where their structure is concentric. Secondary wood is but feebly developed. The next stage in the evolution of these forms away from the *Heterangium* type is furnished by *Medullosa anglica*, which is polystelic with normally three steles each developing secondary wood. The stems were as much as 7 or 8 centimeters in diameter and bore spirally arranged decompound fronds with decurrent petioles. Many adventitious roots were formed.

Without stopping to dwell on the histological details we pass to the exceedingly complex *Medullosas* of the Permian, in which the steles become very numerous and are differentiated into inner "star rings" and outer "plate rings" systems, the latter forming a peripheral zone which is an almost closed woody cylinder. Successive extrafascicular zones of wood and bast were developed in several species. The leaf traces which are at first concentric break up into strands with external protoxylem, several from different levels of origin entering each petiole. The peculiar arrangement in these later *Medullosas* is a necessary outcome of large polystelic stems with secondary thickening and appears to have constituted a rather impractical experiment in attempting to develop secondary thickening around numerous steles in a single stem. If the theory advocated by Worsdell, Chodat, and others is substantiated, it would appear that certain of the Permian *Medullosas* solved this problem in the mechanics of stem structure by suppressing the centripetal portions of the steles, while the

centrifugal and continuous portions characterized forms which passed by gradations into the Cycadophytes. Scott and Solms Laubach, on the other hand, regard the Medullosaceae as a highly differentiated derivative of a Heterangiumlike ancestor which became so specialized that it became extinct during the Permian. Other genera that appear to belong to this family are Colpoxylon, Rhexoxylon, and possibly Steloxylon, all based upon fragments of petrified stems from the Paleozoic of Europe, Africa, and Asia.

Medullosa petioles are referred to the genus *Myeloxylon* and structural material has been described from both Europe and America. The foliage of Medullosa was of the frond types known as Neuropteris, Alethopteris, and Linopteris; all of which were exceedingly abundant and cosmopolitan in the later Paleozoic floras. Impressions from the Scotch Carboniferous show large Rhabdocarpus seeds attached to the fronds of *Neuropteris heterophylla* and similar but still larger seeds attached to Belgian specimens of *Neuropteris obliqua*. *N. Schlehani* and *N. auriculata* have also been shown to have been seed-bearing.

The microsporangia appear to have been four valved and terminal on naked pedicels in *N. heterophylla* or marginal on orbicular or cuneate pinnules as in *Potoniea*, *N. gigantea* and *N. Carpentieri*. Although no seeds have been found in actual connection with Alethopteris there are good reasons for believing that some species at least (e. g., *A. lonchitica*, *A. Serlii*) bore seeds of the Trigonocarpus type. The latter, which are often exceedingly common as impressions and casts, as described from petrified material are elongate-oval radially symmetrical. The testa is thick and consists of an outer flesh (sarcotesta) a shell (sclerotesta) and an inner flesh. The shell has three longitudinal ribs which characterize the seeds when preserved as casts after the decay of the outer flesh. Less prominent lines are intercalated between the main ribs. There was a long triangular micropylar canal leading to a small pollen chamber in the apex of the nucellus and the latter is free to the base.

Other genera that may represent sporangia of different types of Medullosaceae are Codonotheca, Schützia, Whittleseya, Dolerophyllum, and Ottokaria (?).

The bulk of the remaining types referred to the Pteridospermatophyta are based upon anatomical studies of stem or petiole fragments ranging in age from the Devonian (*Kalymma*) to the Permian and will not be described in the present connection. In addition to these, several types of fronds formerly referred to the ferns have been proved to be seed-bearing, as, for instance, fronds referred to *Pecopteris Pluckenetii* but probably representing *P. Sterzelii*, in which the slightly reduced pinnules bore terminal oval seeds with a thick

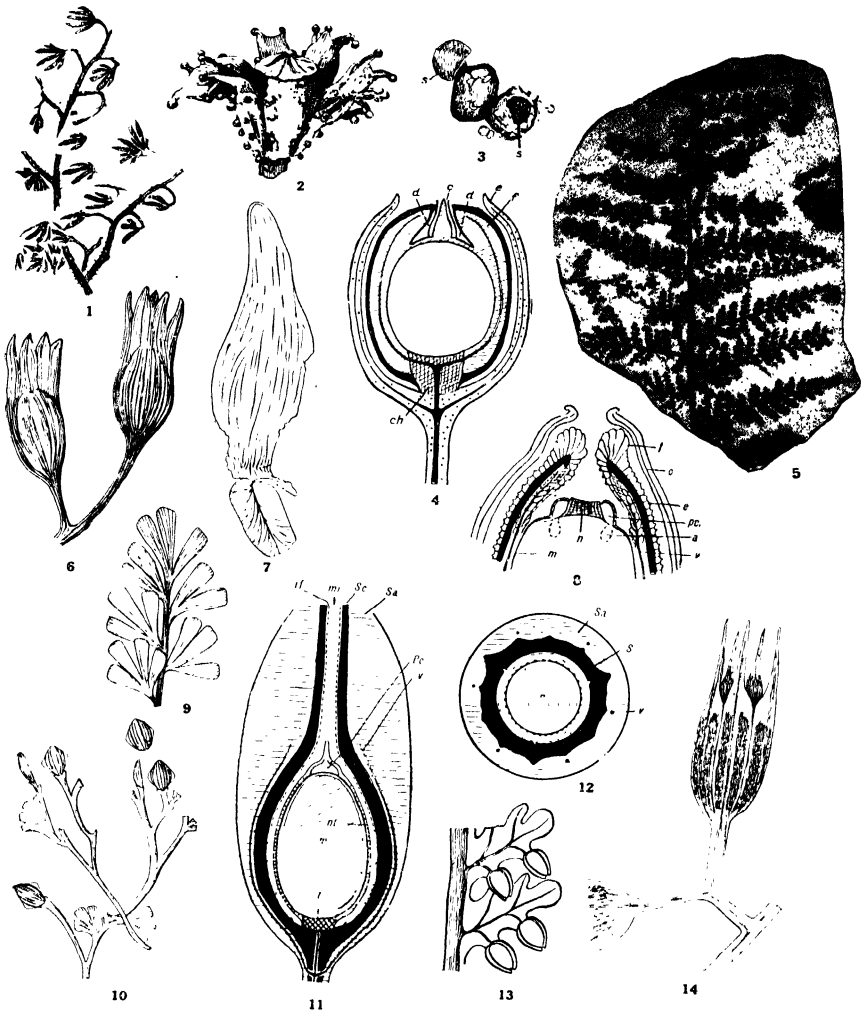


FIG. 15.—DETAILS OF ORGANIZATION OF SOME OF THE DIFFERENT TYPES OF SEED FERNS.

1. *Calymnothera stangeri* Stur. Involucres of megasporangia or seeds (after Stur).
2. Restoration of *Lagenostoma lomaxi* (after Oliver).
3. Microspores of *Lagenostoma ovoides* (after Benson).
4. *Lagenostoma lomaxi* in median longitudinal section (after Oliver).
c, micropyle; d, space between nucellus and integument; e, cupule; f, integument; ch, chalaza.
5. *Sphenopteris hoeninghausi* (after Schimper).
6. *Lagenospermum sinclairi* (after Arber).
7. *Neuropterocarpus kidstoni* (after Kidston).
8. *Sphaerostoma ovale* (after Benson):
e, cupule; e, f, integument; v, vascular bundle in integument; n, upper part of nucellus; m, megaspore; a, archegonia.
9. Sterile pinnae of *Ancimites fertilis* from the Pottsville of West Virginia (after White).
10. Seed bearing pinnae of the preceding.
11. Median longitudinal section of *Trigonocarpus parkinsoni* (after Scott).
12. Transverse section of preceding:
Sa, sarcotesta; Sc, sclerotesta; if, inner flesh; ml, micropyle; m, megaspore and prothallus; Pc, pollen chamber; v, vascular bundles; t, tracheal disk; nt, tracheids of nucellus.
13. Seed bearing pinnae of *Pecopteris* (after Grand'Eury).
14. *Pterispermotrobis bifurcatus* from the Carboniferous of New Brunswick (after Stopes).

sarcotesta giving the impression the appearance of having narrow wings. This discovery is of special interest since typical Pecopteris fronds have been shown to have constituted the foliage of Psaronius (an undoubted fern) and they frequently show fern fructification of the Asterotheca or Scoleopteris type. A second fern, *Aneimites fertilis*, from the Appalachian Pottsville had small bilaterally symmetrical seeds on the somewhat reduced pinnules, the fleshy sarcotesta giving the impressions the appearance of having narrow wings. Other associations of seeds and fronds not found in organic union are the frond species *Eremopteris artemisaefolia* and the seeds *Samaropsis acuta*, the frond species *Aneimites bellidulus*, and the seeds *Lagenospermum Arberi*.

It has been suggested that the Gondwana genera Glossopteris and Gangamopteris were Pteriosperms, but there is as yet no basis for this view. The peculiar Permian frond genus of Asia and North America known as Gigantopteris is found in constant association in the latter country with flat cordiform alate seeds borne in the concavity of an obovate reduced pinnule with the Gigantopteris venation, and associated with these are detached two ranked strobiloid organs consisting of similar bract-like pinnules bearing small oval pendent microsporangia—not true cones, but definitely more strobiloid than any demonstrated Pteridospermophyta.

It is evident that the Pteridospermophyta constituted a large and varied plexus of synthetic seed plants, our knowledge of which is too imperfect to warrant an extended discussion of their phylogenetic relations. That they were descended from the ferns is obvious, but whether from the more complex Cœnopteridae (e. g., *Asterochlaena*), through the polystelic Medullosaceae or from a simple protostelic form of Botryopteraceae through Lyginopteris is debatable. They seem to show an as yet undemonstrated relationship with the Paleozoic Marattiaceae. Within the phylum, Scott regards them as showing two lines of descent: One through the evolution of a single stele and leading in the direction of the Cycadophytes, and the other toward polystely which eventually became extinct. Chodat, on the other hand, regards Lyginopteris as a true fern with specialized megasporangia without higher issue, while he considers the Medullosaceae as the ancestors of the Cycadophyta.

Whatever the details of descent turn out to be the Pteridospermophyta in some of their forms undoubtedly stand in an ancestral relationship to the Cycadophytes, and they may well have merged in their earlier manifestations with the same stock that gave rise to the Cordaitales and Ginkgoales.

Following is a summary of the types which are probably referable to the *Pteridosperm* phylum:

- Lyginopteraceae*—*Lyginopteris* (*Telangium* *Lagenostoma* *Lagenospermum*, *Pterispermostrobus*) *Sphenopteris*, *Calymmotheca*, etc., *Heterangium* (*Sphenopteris* *Sphaerostoma*, etc.).
- Medullosaceae*—*Medullosa* (*Myeloxylon*, *Neuropteris*, *Alethopteris*, *Linopteris*, *Trigonocarpus*, *Codonotheca*, *Schützia*, *Whittlesaya*, *Dolerophyllum*, etc.).
Colpoxylon.
Rhexoxylon.
Sutcliffia.
- Steloxyleae* (?)—*Steloxylon*.
- Megaloxyleae*—*Megaloxylon*.
- Rhettinangieae*—*Rhettinangium*.
- Stenomyeleae*—*Stenomyelon*.
- Cycadoxyleae*—*Cycadoxylon*.
Ptychoxylon.
- Calamopityeae*—*Calamopitys* (*Kalymma*).
Eristophyton.
- Cladoxyleae*—*Cladoxylon*.
Völkella.
- Protopityeae*—*Protopitys*.
- Incertae sedis*—*Pecopteris pluckenettii*, *Eremopteris artemisiaefolia*, *Wardia*, *Adiantites bellidulus*, *Ottokaria*, *Strobilites*, *Gigantopteris*, *Glossopteris* (?), etc.

PHYLUM CYCADOPHYTES.

No existing group of plants has excited more interest in recent years than the existing cycads (order Cycadales). Before the peculiarly organized Mesozoic forms were understood, the wealth of foliar impressions of cycad-like fronds in the Mesozoic rocks throughout the world and similar less abundant remains in the later Paleozoic, led to the conclusion that the cycad line was simply another example of an ancient, persistent, rather uniform stock derived from the ferns, whose existing representatives were the straggling survivors of a type which attained its maximum development in the older Mesozoic. The researches of Carruthers, Solms Laubach, Nathorst, Lignier, and Wieland have shown that the group was large and diversified, and includes at least two extinct orders very different from the existing cycads; that its origin is to be looked for among the seed ferns rather than the true ferns; and that existing cycads represent relatively modern and never very abundant derivatives of this ancient stock.

In sketching the morphology of the Cycadophytes the reader has to bear in mind that we are dealing with an extensive group that appeared in the record as early as the Carboniferous (Westphalian) and continued to the present, and that aside from the recent forms and a few exceptional fossil forms like the Rhaetic *Wielandiella* and the

Lower Cretaceous Cycadeoids and Williamsonias, we have only the remains of foliage as a clue to relationships, and practically no information regarding anatomy or fructifications; the latter we infer from the analogy of known forms were highly variable.

Various attempts at a natural, or at least a logical, classification of the Cycadophytes have been attempted. These range from regarding the phylum as consisting of two subordinate groups: the Cycadales, and the Mesozoic Cycadeoides and Williamsonias as a second order—the Bennettitales, to those recognizing such ill founded groups as the Nilssoniales, based upon cuticular characters. Without wishing to depreciate the importance of any available features in the study of fossil forms, all of which are valuable, or of failing in recognition of the praiseworthy work of Nathorst, Thomas, Bancroft, and others upon cuticles, it may be suggested that cuticles can scarcely be regarded as affording ordinal criteria. In the case of the proposal of such a group as the Nilssoniales, the variation in detail of these features and their similarity to what obtains rather uniformly in other groups of xerophytic gymnosperms, shows conclusively that they represent convergence due to habitat. A tendency, especially among botanists, to regard the cycadeoids as the dominant and progressive fossil type and to overestimate the degree of relationship between them and their contemporaries, the Williamsoniales, is also to be deprecated.

It must be recognized, entirely aside from the degree of convergence or divergence of fructification morphology, that the cycadophyte stock as it was derived from the pteridosperms was a relatively slender stemmed branching type, corresponding to the more primitive Williamsonia type as exemplified by the Triassic Wielandiella. Nothing is known of the anatomy or fructifications of many of the so-called Williamsonia genera such as Pterophyllum, Plagiozamites, Anomozamites, etc. Analogy would lead to the view that the floral and stem morphology had not become stereotyped in this order and exhibited considerable diversity, sufficient to include Podozamites on the one hand, and Williamsonia on the other. It would seem that the most natural arrangement of the phylum is one that regards the main line of descent from which the more specialized or reduced branches were given off at different times as a separate order, the Williamsoniales, which was the long existent and cycadophyte plexus, from which two other orders, the Cycadales and the Cycadeoidales, were derived.

Quite naturally the Williamsoniales that are nearest the points of origin of the Cycadeoidales, or Cycadales, will show great similarities in their fructifications, but any arrangement that throws these points of contact into one order and recognizes such quasi groups as

Nilssoniales or Dioöniales, effectually obscures the fundamental plan of evolution of the phylum, if its history has been at all like that just outlined. The name Williamsoniales is unfortunate, and probably it would be better to use Hemicycadales (Wieland).

As sketched in the following paragraphs the Cycadophyta are somewhat arbitrarily segregated into three subordinate groups: The aberrant Cycadeoidales, which are not as far removed from the second group, the Mesozoic and existing Cycadales, as formerly was thought to be the case. The third group, for which the inappropriate name Williamsoniales is retained, includes the balance of the Cycadophytes. It is not a compact group, and the progress of discovery will doubtless show it to be unnatural. In its beginnings it approximates the Pteridospermophyta and also shows points of possible contact with the Gnetales and Ginkgoales. In its more evolved members (e. g., *Williamsonia*) it approximates the Cycadeoids to such an extent that Wieland and other authorities group the former and the latter together. The two points of view are entirely in agreement regarding the facts and differ merely in the placing of the boundary between the two groups, a not very serious difference in an evolving series of forms.

Although in *Cycadeoidea Gibsoniana*, the species in which the floral organization was first made known, only ovulate organs were discovered, the much fuller American material leads to the inference that the flowers were normally bisporangiate.

The Cycadeoidales appear to represent an evolution from the older Williamsoniales stock, and according to our present knowledge, they are confined to the Jurassic and Lower Cretaceous. Their prevalently tuberous trunks are individually abundant in a silicified condition in certain sandy strata of those ages, particularly in the Portland Dirt Bed of the Isle of Wight, in the Patuxent formation of Maryland, and the Morrison beds of the Freezeout Hills in Wyoming. By far the largest number have been found in the similar strata of the Lakota formation, which outcrops in the Black Hills rim. Similar remains in less abundance have been found in France, Italy, Galicia, and elsewhere. Their wonderful preservation and exceptional morphological features have resulted in unusually painstaking researches which have shown that the group as a whole was one of rather limited variation and stereotyped organization, relatively no more abundant in Jurassic and Lower Cretaceous times than are the Cycads in existing floras.

The salient features, briefly enumerated, are a tuberous or short columnar stem, sometimes an aggregate of tuberous stems, as in some species of *Encephalartos*. The stem was encased in a heavy armor of persistent leaf bases, which largely obviated the necessity for the development of a thick zone of mechanical woody tissue in the stem.

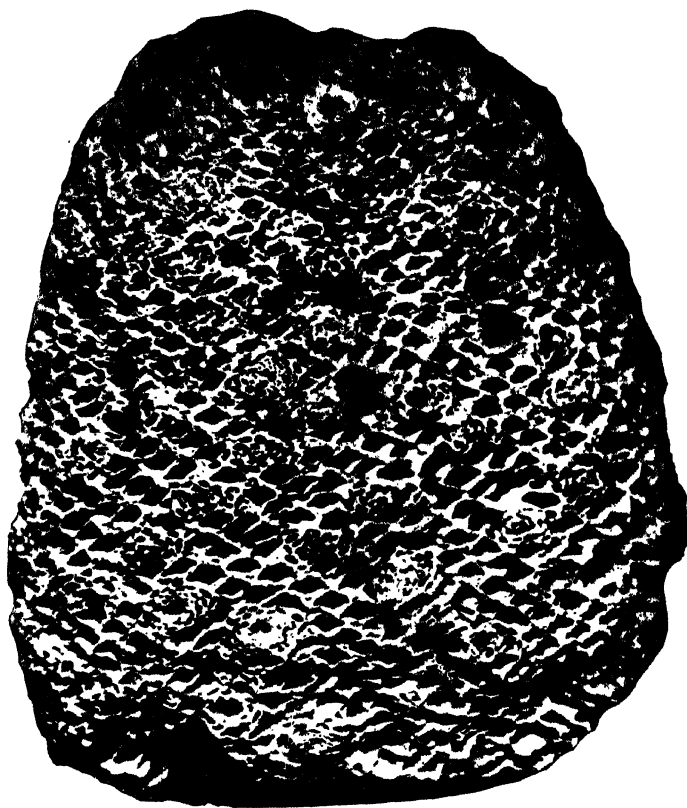


FIG. 17.—THE HISTORIC JOHNS HOPKINS CYCAD, *CYCADEOIDEA MARYLANDICA* (FONTAINE), THE FIRST PETRIFIED TRUNK DISCOVERED IN AMERICA, X₁₅.

The interstices of leaf bases were filled with multicellular scales (unicellular hairs in the Liassic *U. Micromyela* Morière) corresponding to the ramentum of ferns, in some cases (as in the genus *Cycadella*) very long and enclosing the whole trunk in a felt-like mass. This ramental covering appears to have facilitated their subsequent silicification, so that normally the fossil trunks show the ramental areas as prominent partitions, separating the subrhombic angular cavities left by the leaf stalks which decayed or were shed before fossilization. Among the leaf bases occur numerous short axillary branches each terminated by a solitary fructification or flower, as Wieland terms the latter. The anatomy of the stem is much like that of the cycads. There is a thick cortex, a comparatively thin vascular cylinder and a very large pith containing secretory sacs rather than gum canals. The vascular bundles are collateral, the protoxylem is next the pith (endarch), and the few spiral marked tracheids are soon replaced by scalariform tracheids which appear to characterize the phylum, although pitted tracheids are recorded in *Cycadoidea micromyela*. In the leaves, however, the structure is mesarch, suggesting their pteridophytic ancestry. The leaf traces are single and direct and thus more simple in their arrangement than in existing cycads.

The axillary branches bear reduced leaves or bracts spirally arranged, and are of a length to bring the terminal flower at about the general level formed by the persistent leaf bases. The branch axis expands into a subhemispherical or conical receptacle. At its base and immediately beyond the enclosing bracts was inserted a whorl of compound microsporophylls, united into a continuous sheath proximad, expanding distad into a bipinnate frond with alternate pinnae, all of which, except the apical and basal pairs, bearing two rows of synangia, suggesting those of a marattiaceous fern, the whole greatly resembling a fertile fern frond rather than a verticil of stamens, and like the former circinate in vernation. The surface of the receptacle above the staminate collar is beset with slender pedicels, each bearing at its extremity a single orthotropous seed, the interspaces packed with sterile appendages known as interseminal scales, which expand apically so that only the micropylar part of the seed reaches the surface, and the whole is compact and simulates a closed pericarp. Before proceeding with the description of the seeds, it may be well to state that of the various morphological homologies that have been advanced, that which regards the interseminal scales as greatly reduced foliar appendages and the seed-bearing pedicels as reduced megasporophylls seems the most probable.

The whole fruit-like body is ovoid or turbinate in shape, several centimeters in length, the surface a mosaic of the expanded tips of

the interseminal scales, between which the micropylar tubes of the seeds protrude. The microsporophylls are only preserved in immature strobili. They have disappeared at a later period, but their former presence can usually be inferred from the basal shoulder that marks their insertion on the receptacle. The probabilities are that all the cycadeoids were bisporangiate, although this is disputed in the case of some species. The seeds are very small as compared with those of living cycads and have a two or three layered testa, prolonged upward into a micropylar tube, the outer palisade layer of which at the shoulder where it joins the seed being expanded by radial extensions, forming five or six radial wings. The cavity of the seed is completely filled by a large dicotyledonous embryo which in its development, unlike any living gymnosperms, destroys all of the endosperm.

A variety of cycad fronds are found in the deposits which have yielded the petrified trunks, but our information regarding their actual foliage is furnished by small unexpanded petrified material which shows pinnate fronds of the *Zamia* type, circinate in vernalia, with erect pinnules. The number was small in *Cycadella*. In *Cycadeoidea ingens* there were 60 to 100 pairs of linear or slightly spatulate pinnules, and the truncate pinnate fronds are estimated as having been several feet in length at maturity. It seems probable from the large number of cones in the same stage of development in some trunks and their complete absence in other large trunks that seed formation was the culminating event of many seasons of vegetational activity, possibly occurring but once at the maturity of the plant, but more probably repeated at increasing intervals throughout life. In the historic Johns Hopkins Cycad shown in the accompanying figure 17 there are 58 strobili on the face figured.

Fronds indistinguishable from those of cycadeoids are cosmopolitan from the Triassic to the Upper Cretaceous, but there is no means of determining to what an extent they belong to the cycadeoids, and the probabilities are strongly in favor of considering most of them as the fronds of the order that I have termed the Williamsoniales.

The Williamsoniales comprise a much more protean and long-lived group of forms, unfortunately known almost entirely from impressions. They appear in the later Paleozoic in the genera *Plagiozamites*, *Pterophyllum*, and *Sphenozamites*; are very prominent in the Triassic, Jurassic, and Lower Cretaceous; and are still present but in reduced numbers in the Upper Cretaceous after the cycadeoids had become extinct. The nature of their remains precludes a concise summary of their features. Both the very abundant foliar remains as well as such fructifications as have been preserved indicate a much wider variability than among the other two orders of cycadophytes. The sole feature that at present can be considered as probably char-

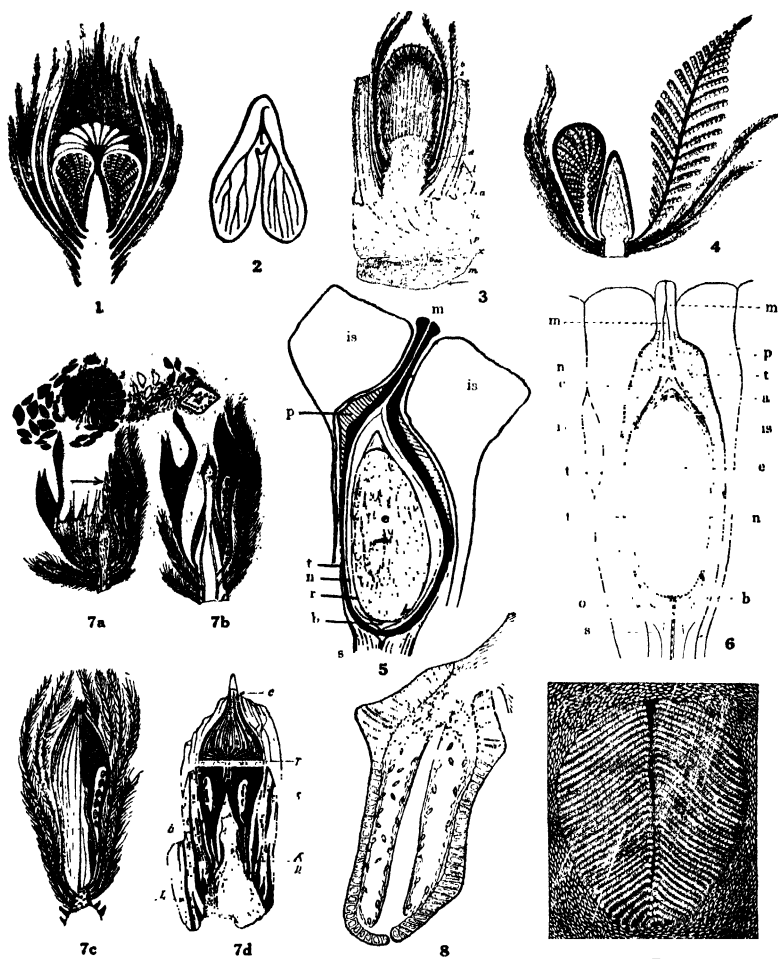


FIG. 16.—Fructifications of the Cycadeoidales.

1. Restoration of an unexpanded fructification of *Cycadeoidea* (after Wieland).
2. Embryo of *Cycadeoidea* showing vascular bundles (after Wieland).
3. Median longitudinal section of ovulate strobilus of *Cycadeoidea* (after Wieland):
m, pith; x, xylem; p, phloem; e, cortex; a, insertion of leaf; b, bracts; s, seeds; l, leaves; d, collar for insertion of microsporangiate disk.
4. Restoration of complete and partially expanded fructification of *Cycadeoidea* (after Wieland).
5. Section of seed and adjacent interseminal scales of *Cycadeoidea turrita* (after Wieland):
is, interseminal scales; s, pedicle of seed; e, embryo; r, megaspore membrane; n, nucellar sac; t, inner layer of testa; p, exterior layer of testa "blow off"; m, micropylar opening and canal; b, chalaza.
6. Section of seed and adjacent interseminal scales of *Cycadeoidea morierii* (after Lignier):
a, archegonia ?; c, pollen chamber; t and tl, inner and outer testa; o, peduncle.
- 7a, b, c, d. Diagrammatical restoration of fructification of *Cycadeoidea colossalis* (after Wieland):
A, transverse section above the receptacle showing the bracts (black), a petiole with vascular bundles ramenta, and (1—10) the wings of the microsporophylls. B, C, longitudinal section of flower showing the receptacle with the small megasporophylls, the staminate disc, with winged microsporophylls and synangia, and the terminal brush of interseminal scales (indicated by the arrow in B). The megasporophylls and synangia are represented larger than the actual size. D, this shows on one side the dome-like arrangement of the microsporophylls and, on the right, a microsporophyll in side-view. E, longitudinal section as far as the plane T surmounted by the apex of the collection of microsporophylls, c; s, microsporophyll with synangia; A, recurved apex of microsporophyll; B, bracts; D, insertion of disc; L, outer bracts next the petiole bases.
8. Longitudinal section of synangium of *Cycadeoidea dactotensis* (after Wieland).
9. Transverse section of a partially emergent but still folded frond of *Cycadeoidea ingens* deeply imbedded in ramentum (after Wieland).
10. Transverse section of a partially emergent but still folded frond of *Cycadeoidea ingens* deeply imbedded in ramentum (after Wieland).

acteristic of the order is the relative slenderness and elongation of the stem and the frequency with which it branched, often dichotomously.

It is not possible to consider the various foliar types in the limits of the present paper, a subject requiring much study and never adequately discussed, and only a few of the more representative types will be mentioned. Among these one of the most remarkable is the genus *Wielandiella* from the Rhaetic of Sweden. *Wielandiella* had an elongated slender stem not over 2 centimeters in diameter, with repeated dichotomies, prevailingly naked except in the region of the forks, where it bore spirally arranged, rather reduced fronds of the *Nilssonia* or *Anomozamites* types. In each fork was a sessile fructification surrounded by bracts. These fructifications are met with in two forms, probably representing different ages and states of preservation. In the one it consists of a small pyriform axis separated from the peduncle by a swollen striated collar bearing oval microspores on the surface of greatly reduced scalelike sporophylls. Ovulate structures on the pyriform axis appear to have been vestigial. In the second type the axis is hidden by the linear bracts but its surface reveals a regular pattern of interseminal scales between which the micropylar tubes project, indicating an ovulate organization like that of the cycadeoids and *Williamsonia*.

Another old genus is the Rhaetic genus *Cycadocephalus*, also from Sweden, and based on impressions of a large fructification 10 centimeters long and 7 centimeters in diameter. The peduncle is slender and shows no leaf or bract scars. No trace of a central ovulate receptacle is discernible, the head consisting of a cluster of linear microsporophylls with a keellike midrib on their inner faces, and bearing on either side of this midrib linear pointed synangia.

A third Rhaetic genus is *Weltrichia* from Franconia, based upon a funicular fructification, the cup of which was formed by the crescent bases of about a score of broadly linear microsporophylls, the whole 10 centimeters in length and 9 centimeters in diameter. The free lanceolate apical portions of these bear linear appendages 5 to 8 millimeters long attached to their inner faces, comparable with the synangia of *Cycadocephalus*. No traces of ovulate structures are known, so it can not be determined whether either *Cycadocephalus* or *Weltrichia* were unisexual or bisexual. An elaborate account of *Weltrichia* by Schuster, largely imaginative, supplies a remarkable assemblage of features that are best ignored until corroborated by some reliable student.

As previously mentioned, a variety of frond genera of late Triassic, Jurassic, and Lower Cretaceous ages are found from Japan and New Zealand on the east to California and Alaska on the west, and from Franz Joseph Land, Spitzbergen, and Greenland on the north to Graham Land on the south. No continent is without an

abundant representation. In the present abridged account a mere mention of the more important genera that have been recognized must suffice. Associated with these frond genera at many localities, particularly in India, England, and southern Mexico, are the objects commonly referred to the genus *Williamsonia*.

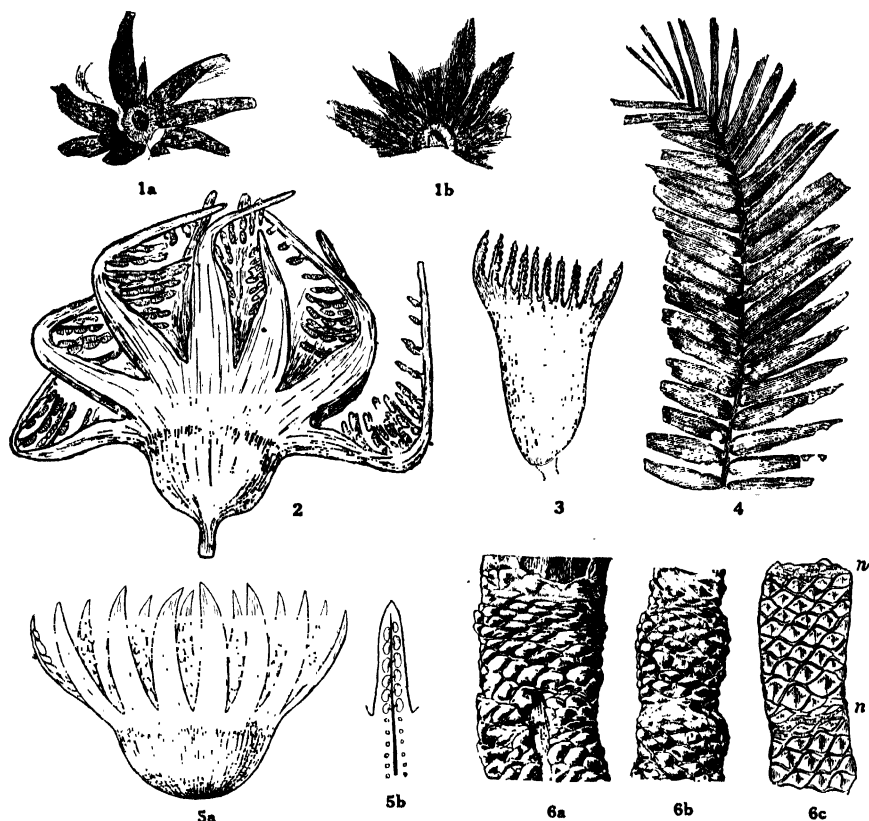


FIG. 18.—Types of Williamsoniales.

- 1a, b. *Williamsonia virginienensis* Fontaine from the lower Cretaceous of Virginia (after Fontaine).
2. *Williamsonia spectabilis*. Restoration after Thomas, Jurassic of England.
3. Restoration of *Williamsonia mexicana* from the Liassic of Mexico (after Wieland).
4. Frond of *Zamites gigas* from the Jurassic of England (after Seward).
- 5a. *Williamsonia whitbiensis* microsporangiate disk from Jurassic of England (after Nathorst).
- 5b. Sporophyll of same showing insertion of synangia.
- 6a. *Bucklandia milleriana* from the Jurassic of Scotland (after Carruthers).
- 6b. *Bucklandia (Yatesia) joassiana* from the Jurassic of Scotland (after Carruthers).
- 6c. *Williamsonia* sp. from the Liassic of Mexico (after Wieland).

The most celebrated of these is perhaps *Williamsonia gigas*, discovered early in the last century in the Jurassic outcrops along the Yorkshire coast, and the basis for Williamson's historic restoration. These have been found in organic union with foliage and stems. The stems (*Bucklandia*) were slender, 5 centimeters in diameter, covered with rhomboidal leaf scars, with a crown of *Zamia*-like fronds

about 2 feet long, and bearing at the summit slender peduncles 20–30 centimeters long, covered with spirally-arranged scale leaves, and terminated with an ovulate receptacle bearing pedicellate seeds similar to those of *Cycadeoidea* surrounded by bracts or sterile sporophylls united proximad to form a disk or cup. No trace of microsporophylls are certainly known in this species, although the probabilities are that it was bisporangiate, in fact, certain staminate disks have been referred to this species by various students.

Naturally, a very large number of different species of *Williamsonia* have been described from a variety of Mesozoic horizons and localities, but few of these show essential features or have been exhaustively investigated. A very characteristic form (*W. virginensis*) occurs in the Lower Cretaceous of Virginia and another in the Upper Cretaceous of Delaware.

Among the better-known forms are *W. spectabilis* from the Yorkshire Jurassic, which shows a funicular disk prolonged into linear lanceolate microsporophylls bearing on their inner faces fertile pinnae carrying reniform synangia. A central ovulate receptacle is wanting. *W. whitbiensis*, also from the Yorkshire coast, is similar to the preceding, but the fertile pinnae are reduced and the reniform synangia are borne on either side of the midrib along the inner face of the free part of the microsporophylls. Still another type is *W. mexicana* from the Lias of Southern Mexico in which the cup is deeply campanulate with 10 short narrow free lobes bearing two rows of lateral synangia.

The only petrified *Williamsonia* known is the imperfectly preserved *W. scotica* from the Jurassic of Scotland, which shows hairy bracts, no traces of microsporophylls, and a central receptacle consisting of interseminal scales and pedicellate seeds exactly similar to *Cycadeoidea*.

An interesting and more reduced type, whose affinities indicate the survival to the middle Jurassic of the *Wielandiella* type, is one made the basis of the genus *Williamsoniella*. If the various parts are correctly correlated they show slender, frequently dichotomous stems bearing scattered leaf scars and believed to have borne the associated type of foliage known as *Taeniopteris vittata*. In the stem forks are pedunculate bracteate fructifications consisting of a whorl of cuneate microsporophylls bearing five to six sessile reniform synangia on either side of the inner keel. Within the whorl of microsporophylls a pyriform receptacle with a sterile crown is covered with small interseminal scales and short-stalked seeds like those of *Williamsonia* and *Cycadeoidea*.

Remarkably well-preserved fronds from Greenland and elsewhere described as *Cycadites* have recently been shown to possess a double midrib separated by a stomatal groove, and these forms have con-

sequently been made the basis for a new genus, *Pseudocycas*, although nothing is known of the plants which bore these anomalous fronds.

A frond genus that deserves mention is *Podozamites*, to which a very large number of often detached pinnules have been referred, some of which are with difficulty distinguished from the coniferophyte genera *Nageiopsis*, *Araucaria*, etc. These are widespread and more or less abundant from the Triassic to the Upper Cretaceous. In the more perfect specimens *Podozamites* shows a slender rachis, with somewhat irregularly spaced parallel veined lanceolate pinnules, often deciduous. *Podozamites* may well be composite. In



FIG. 19.—Restoration of the Jurassic *Williamsoniella* (after Thomas).

a, vertical section of flower, $\times 4$; b, microsporophyll from side, $\times 1$; c, same in transverse section.

certain species the pinnules appear to be borne on definite short shoots, and the associated fructifications (*Cycadocarpidium*) consist of loose cones of sporophylls, much like the vegetative leaves, and bearing proximad, two ovules with pointed wing-like appendages. *Podozamites* in some of its forms may thus constitute a point of contact between the cycadophytes and coniferophytes, or it may really belong with the latter phylum and have no cycadean relationship.

The Cycadales have tuberous or columnar, sometimes subterranean, sparingly or not at all branched stems, covered with persistent leaf bases, bearing a crown of large compound leaves and apparently terminal (truly lateral), dioecious strobilae. The cortex is thick, the

vascular cylinder thin; and the pith large. Bundles are collateral and endarch in the stem, but often mesarch and even concentric in the leaf traces and strobilar axes. The leaf traces girdle the stem, entering leaves on the opposite side from which they separate from the vascular cylinder. Wieland has unquestionably shown that the relationships between the existing and the two extinct orders are closer than was formerly supposed.

The existing cycads constitute a rather compact group of nine genera and about 110 species indigenous in the warmer regions of both hemispheres—*Cycas* with some 16 oriental species and *Zamia* with about 30 occidental species being the dominant genera. Besides *Zamia* the genera *Microcycas*, *Dion*, and *Ceratozamia* are American; *Encephalartos* and *Stangeria* are African, while *Cycas*, *Macrozamia*, and *Bowenia* are Asiatic or Australian. In individual abundance they do not play a leading rôle in any forest assemblage, although the small *Stangeria paradoxa* forms thickets in southeastern Africa and *Macrozamia spiralis* forms a scrub over considerable areas in eastern Australia. For trunk-forming plants they are inconspicuous and vary from the dwarf *Zamias* with underground stems or epiphytic forms to some of the species of *Cycas*, which reach a height of 20 meters and live to a great age.

The stem consists of pith, wood, cambium, and phloem, enveloped in a thick cortex ending in periderm and giving rise to a thin bark, but supporting an investiture or armor of old leaf bases, persistent or not, according as the growth of periderm affects its excision. The pith occupies one-third the diameter of the stem. It is extremely parenchymatous and frequently affords commercial starch. Mucilage canals traverse the pith, cortex, and rays. The pith is traversed by gum canals and by anomalous cauline vascular bundles in *Encephalartos* and *Macrozamia* and by peduncular bundles in *Dion*, *Stangeria*, *Ceratozamia*, *Zamia*, etc. The wood falls into two types. In *Zamia*, *Dion*, *Stangeria*, *Ceratozamia*, and *Microcycas* (?) it is what is known as monoxyletic, i. e., there is a thin and more or less open system of collateral bundles and no persistent cambium or marked secondary thickening. Contrasted with this, *Cycas*, *Macrozamia*, *Encephalartos*, and *Bowenia* are polyxyletic and develop a succession of imperfect cortical cambiums which form xylem zones that are often more or less inverted, as in *Macrozamia* and *Bowenia*, thus suggesting comparisons with such Pteridosperm genera as *Medullosa*.

The Cycadales and presumably the majority of the fossil cycadophytes send down a primary root, which continues as a taproot, often approaching the trunk in size. All the forms have compound leaves. In most genera they are simply pinnate, but in *Bowenia* and certain species of *Macrozamia* and *Cycas* the pinnules are further sub-

divided, giving them a graceful fernlike appearance. This is exhibited in *Stangeria* in another way. Each pinnule has a thick midrib with several vascular bundles, and the broad lamina with prominently toothed margins is traversed by dichotomously branching lateral veins running to the margins, which give it such a fernlike appearance that the first specimens of the foliage to fall in the hands of botanists were described as a new species of fern of the genus *Lomaria*. In *Cycas* the narrow pinnules have a midrib with a single large vascular bundle. All the other genera lack a midrib and have the pinnules traversed by subequal longitudinal bundles. The order of development and the venation of the fronds vary from genus to genus.

The leaves are in whorls crowning the stem or the branches in branched forms, giving a strikingly handsome appearance. Each whorl alternates with a whorl of scale leaves. The whorl may consist of but a few to over 100 fronds, varying in size from a length of 10 centimeters to more than 3 meters and the fronds may have but a few to as many as 250 pinnules. The structure is xerophytic and the pinnules generally have entire margins. They vary from lanceolate to linear and acicular. In some *Zamias* and *Stangeria* the margins are serrate. In *Dion* they are thorny, and in *Encephalartos* they are inequilaterally lacerate.

A feature reminiscent of ancient habits and shared only by *Ginkgo* among existing seed plants is the fertilization of the egg cells by multiciliated swimming sperm cells.

The histological and morphological details of the Cycadales belong to modern rather than paleobotany and need not be dwelt upon in the present discussion.

Both the staminate and ovulate sporophylls are always aggregated in strobili, which are compact and rather uniform throughout the order, except that in *Cycas* the ovulate strobilus instead of being compacted in a cone consists of rosettes of sporophylls resembling reduced foliage leaves, in which ovules replace the lower pinnae or teeth.

The fossil record of the Cycadales is extremely meager. It includes certain not conclusively determined ovulate cones from the Keuper of Switzerland, resembling those of *Zamia*, and more convincing carpellary leaves, like those of the modern *Cycas*, from the top of the French Triassic (*Cycadospadix hennocquei*), from the Kimeridgian of Italy and Scotland (*Cycadospadix pasianianis*), and from the Rhaetic of Sweden (*Cycadospadix integer*), which demonstrate the presence of true Cycadales in the late Triassic and Jurassic. The Cretaceous records are few and not especially trustworthy. During the Tertiary a few undoubted remains of cycads occur at scattered localities, demonstrating a more extended geographical range than

obtains at present. Thus there are two species of *Zamia* in the lower Eocene along the shores of the Mississippi embayment. A third species occurs in the basal Eocene of Belgium, and a fourth in the late Oligocene or early Miocene of Chile. Oligocene species include a *Zamia* from France, an *Encephalartos* from Greece, and a not certainly identified *Ceratozamia* from northern Italy. The Miocene records include a *Zamites* and a *Cycadites* from Switzerland.

PHYLUM CONIFEROPHYTA.

The Coniferophyta correspond almost exactly to the Gymnospermae of the older students. Their outstanding characteristic is the exposed ovules discovered by Robert Brown in 1827. This feature has ceased to be diagnostic, since it is common to the Pteridospermophyta and Cycadophyta, and is evidently of ancient lineage. Although probably more continuously and abundantly represented in the geological record than any other group of plants, it can not be said that our knowledge of either the comparative morphology or the geological history of the phylum warrants a dogmatic view of their phylogeny.

All the known coniferophytes are woody plants with pronounced secondary growth; nearly all are trees, and it is extremely doubtful if the group ever contained herbaceous forms. They show rather uniform xerophytic structure, due possibly to the character of the water-conducting tissues, or to the evergreen foliage, since of the existing species, only the bald cypress, ginkgo, the larch, and *Glyptostrobus*, are deciduous. They usually can not compete successfully with angiosperms under genial conditions. Structurally the bundles are collateral and a primary persistent cambium develops all of the secondary tissues. The water-conducting tissues are tracheids with bordered pits and true vessels are found only in the Gnetales. Both mega and microspores are normally formed in cones (strobili), which are never bisporangiate.

The Araucariales and Taxales are dioecious, while the Coniferales, Cordaitales, and Ginkgoales are monoecious. The sporophylls follow the leaf arrangement and hence are spiral or cyclic. The staminate cones have two or more sporangia to the sporophyll, hence these are less numerous than in the Cycadophytes. They are exceedingly variable and very characteristic for genera. The ovulate cones are varied and their morphological interpretation has been warmly debated for a century. A digest of the various opinions advanced is given by Worsdell. (*Annals of Botany*, vol. 18, p. 57, 1904.)

Pollination is effected through the agency of the wind (anemophily). The stock is of great antiquity and contemporaneous

groups are to be regarded as divergent or convergent and not directly filiated.

Although very probable, the view that the Coniferophyta is a monophyletic group can not be said to be established. It has been demonstrated beyond reasonable doubt that the Cordaitales, Ginkgoales, and Cycadophytes are alike related to the Pteridosperms and Ferns. In the case of the Coniferales and Araucariales this is not so certain, and some students (Renault, Campbell, Potonié, Seward) consider the latter groups as of Lepidophytic origin. There is a plausible amount of evidence for such an origin for the Araucariales, although such a derivation is not generally accepted. There are, however, insuperable difficulties in the way of including the Coniferales in such a stock, even if this theory be accepted for the Araucariales. The most interesting order from an evolutionary standpoint, the Gnetales, since they seem to form a connecting link with the Amentiferous Dicotyledonae, have an ancestry completely unknown, although they show certain structural and developmental points of contact with the Cordaitales, Ginkgoales, and Cycadophytes.

In the present treatment the coniferophytes are grouped in six orders: Cordaitales, Ginkgoales, Taxales, Araucariales, Coniferales (Pinales), and Gnetales, which are best discussed separately. The oldest of these orders, long since extinct, is the Cordaitales—a knowledge of which is due primarily to the work of Grand'Eury. The Cordaitales were exceedingly abundant and presumably varied at several horizons in the Paleozoic and the synthesis of a study of impressions of their foliage and fructification, pith casts, and petrifications enables us to draw a satisfactory picture of their general appearance and habit, although as yet it is usually impossible to correlate specific foliar impressions with petrified stems and seeds.

They were tall and relatively slender trees with trunks that were frequently over 100 feet in height and unbranched except at the crown, where their spirally arranged foliage of simple and often large parallel veined leaves was displayed. Leaf form has been used as a basis for the three forms genera: Eucordaites, with spatulate blunt tipped leaves often several inches in width and 2 or 3 feet in length; Dorycordaites, with pointed leaves approaching those of Eucordaites in size; and Poacordaites, with narrow linear leaves. The parallel venation, unbranched in Poacordaites but repeatedly forked in Dory- and Eucordaites, suggest monocotyledon foliage and the early writers consequently considered Cordaites as a monocotyledon. Both the wood structure, the floral organs, and the seeds were known long before their true nature was appreciated.

The stem has the general features of a modern conifer, except for the much larger pith, sometimes as much as 10 cm. in diameter,

which was often discoidal as a consequence of the rapid elongation of the stem, so that casts yield characteristic forms described by the early writers as *Artisia* or *Sternbergia*. Structurally the wood,

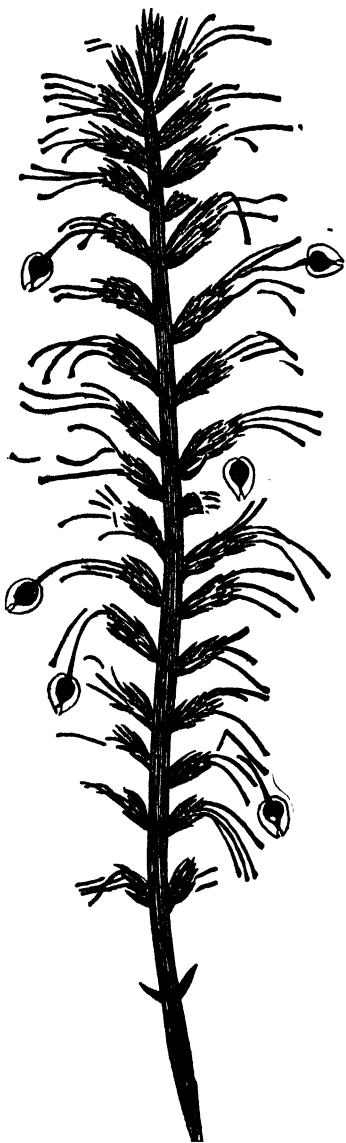


FIG. 20.—*Cordaianthus* from the lower Allegheny formation of Maryland.

commonly known as *Araucarioxylon* or *Dadoxylon*, is centrifugal, with the narrow spiral protoxylem lying at the periphery of the pith, succeeded radially by spiral tracheids, soon passing into scalariform elements, which after an interval pass into pitted tracheids greatly resembling those of the modern *Araucariales*. The bordered pits, which were limited to the radial walls of the tracheids, are usually in two or more rows and so densely crowded in alternating series that they tend to be hexagonal in outline. The rays are narrow; originally they may be three cells wide, but those of the secondary wood are usually one or two cells wide at the most. The phloem, of sieve tubes, parenchyma, and some bast fibers, is like that of modern conifers. The leaf traces were often double, as in some *Pteridosperms* and *Ginkgo*. The bark was thick, but is usually not well preserved. The root system was feebly developed for such large trees, diarch in structure, with a broad zone of secondary wood, conforming in its histology with that of the stem. The leaf structure is comparable to that of a cycad pinnule, with collateral bundles, and the stomata are confined to the lower surface.

The fructifications show considerable variation. The catkins, commonly preserved as impressions under the name of *Cordaianthus*, show an elongated axis with bracteate pedicels bearing the alate bilaterally symmetrical cordate seeds. Petrified material shows the staminate catkins to consist of a thick axis bearing spirally arranged bracts, between which the microsporophylls are inserted, either singly or massed near the apex. Each microsporophyll consists

of a pedicel surmounted by three or four or more vertically elongated pollen sacs which split longitudinally, and contain large pollen grains, which often show a group of prothallial cells. In appearance the ovulate cones are much like the staminate. The axis is thick and clothed with spirally arranged bracts, many of which are sterile. In the axis of others are found short-stalked ovules with bracteoles. The ovules had two integuments—an outer fleshy one, and an inner one which became crustaceous. The ovule shows a nucellus with a large pollen chamber and a beak-like micropylar canal. The pollen grains found in the canal and pollen chamber are larger than those in the pollen sacs, with their mass of prothallial or antheridial cells more extensively developed, and it is hence inferred that the habit of forming pollen tubes had not yet been developed and motile sperms were formed directly. The seeds of numerous species are common as impressions and have frequently been found in a petrified condition. They exhibit considerable variation in size and form and commonly go under the name of *Cordaicarpus*.

Several additional types of Cordaitan wood anatomy are known. These include *Mesoxylon*, of which several species have been described from the English Carboniferous, and which help bridge the gap between Cordaites and the family *Poroxylaceae* of the Carboniferous and Permian. Both *Mesoxylon* and *Poroxylon* develop centripetal xylem in the primary wood. A third family, the *Pityeae*, based on large trunks from the Lower Carboniferous of Scotland, is chiefly distinguished by the wide rays. Other anatomical genera in the Cordaitan plexus include *Callixylon* of the Upper Devonian of Europe and America, *Caenoxylon* of the Russian Permian, *Mesopitys* of the Permian, *Parapitys* of the middle Carboniferous and *Archalaceopitys* of the Lower Carboniferous of Kentucky. Evidently much remains to be learned before these and other as yet unknown Cordaitan forms can be properly allocated. The Cordaitales show clearly their origin from the same ancient plexus that gave rise to the Pteridosperms. They likewise show points of contact with the later coniferophyte orders, especially with the Ginkgoales, Taxales and Araucariales.

The Ginkgoales as a group can be characterized only by the features of the single existing species, and these may be misleading when applied to remote ancestral forms. This obvious conclusion must be borne in mind in the attempts to relate these forms to the ancient Cordaitales on the one hand and the modern Abietineae on the other. Thus the formation of pits on the tangential walls of the tracheids at the end of the annual ring is a purely physiological response to an alternation of growth periods and resting periods and is due to climatic changes, as is the deciduous habit, and it is very probable that neither of these characters was present in early Mesozoic forms

or has any phylogenetic significance. Similarly the paired sporangia appear to represent a reduction from the more numerous sporangia in the Mesozoic species.

The modern *Ginkgo* has a persistent primary cambium, collateral bundles, double-leaf trace, no wood parenchyma, resin ducts in both

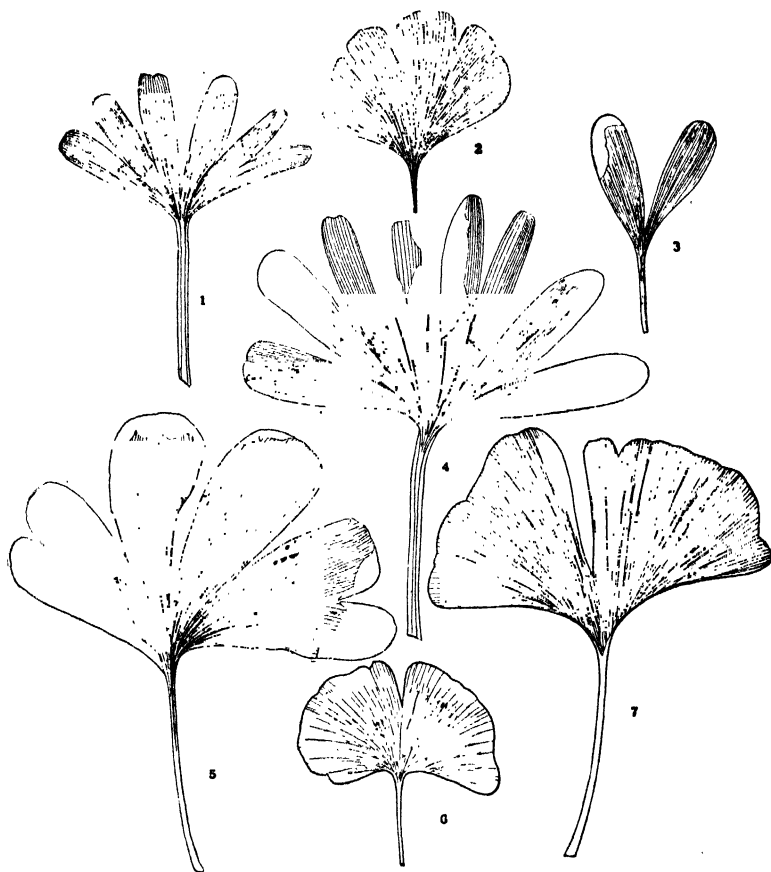


FIG. 21.—Views illustrating the variation in leaf form of the fossil species of *Ginkgo*.

1. *Ginkgo digitata* (Brongn.) Heer. Jurassic of Oregon.
2. *Ginkgo laramiensis* Ward from the Upper Cretaceous of Wyoming.
3. *Ginkgo obtrutschewi* Seward. Middle Jurassic of Chinese Dzungaria.
4. *Ginkgo sibirica* Heer. Jurassic of Oregon.
5. *Ginkgo huttoni magnifolia* Fontaine. Jurassic of Oregon.
6. *Ginkgo adiantoides* (Unger) Heer. Tertiary of Isle of Mull.
7. *Ginkgo adiantoides* from the Fort Union of Montana.

pith and cortex, tracheids with radial opposite pits separated by so-called bars of Sanio. The leaves are comparable anatomically with those of cycads but are simple and deciduous. They are borne on either long terminal shoots or in tufts at the apex of short axillary shoots, the latter habit shared by some fossil species of *Baiera*. The

pollen is slightly winged and is formed in microsporangia, which are normally in pairs, pendent from the expanded tips of sporophylls arranged in loose catkins in the axils of scale leaves at the end of short shoots. The megasporangia are also normally in pairs, although but one ovule matures, and are at the end of a long stalk which is morphologically a shoot and in some Mesozoic species bore more than two ovules. The sperms are ciliated and free-swimming as in the Cycadophytes and Pteridophytes. *Ginkgo* was formerly considered a member of the family Taxaceae, although its resemblance to cycads has long been known. It appears to have been derived from the Paleozoic plexus of Pteridospermophyta and shows points of contact with both the Paleozoic Cordaitales and the Mesozoic Williamsoniales. All three groups probably had similar ancestors, but there is no evidence that the Ginkgoales have been ancestral to any existing group of Coniferales.

The modern *Ginkgo* is the most isolated as well as the oldest existing arborescent form, its stock being represented in the fossil record continuously from the Permian to the present. The leaves are so characteristic that there is little uncertainty regarding their determination, although in some of the older associates referred to the Ginkgoales the foliage simulates such digitate fern fronds as *Schizaea*, and some of these are of questionable identity. The limited space forbids more than a mention of the extinct genera that have been referred to this order and which in some cases do and in other cases do not belong to this stock. Some of these genera are *Ginkgo-phyllum*, *Saportaea*, *Trichopitys*, *Dicranophyllum*, *Rhipidopsis*, *Whittleseya*, *Psymnophyllum*, *Gomphostrobus*, *Trichophyllum*, *Feil-denia*, *Phoenicopsis*, and *Czekanowskia*.

Some of these, such as *Saportaea* and *Rhipidopsis*, seem clearly to represent early variants of the *Ginkgo* type, but the two fossil genera that stand out beyond all question are *Ginkgo* itself and the allied genus *Baiera*, the latter segregated on account of the short petiole and the repeated dichotomy of the leaf blades to form narrow elongate ultimate segments in which the veins no longer fork and because of the more numerous micro- and megasporangia. The modern *Ginkgo* sometimes furnishes instances of more than the usual number of pollen sacs and ovules, and its leaves also frequently become divided to simulate those of *Baiera*.

Both *Baiera* and *Ginkgo* appear as far back as the Permian and become abundant and varied throughout the Triassic, Jurassic, and Lower Cretaceous, where frequently the seeds, immature fruits, and the pollen-bearing catkins, as well as the leaves, are found fossil.

Baiera attains its maximum range somewhat earlier than *Ginkgo*, and, as the accompanying map shows, its distribution appears to

have extended beyond the known range of *Ginkgo* in South America, South Africa, and New Zealand. It is evidently a waning type during the Upper Cretaceous and becomes entirely extinct before the close of that period. *Ginkgo*, on the other hand, has been found

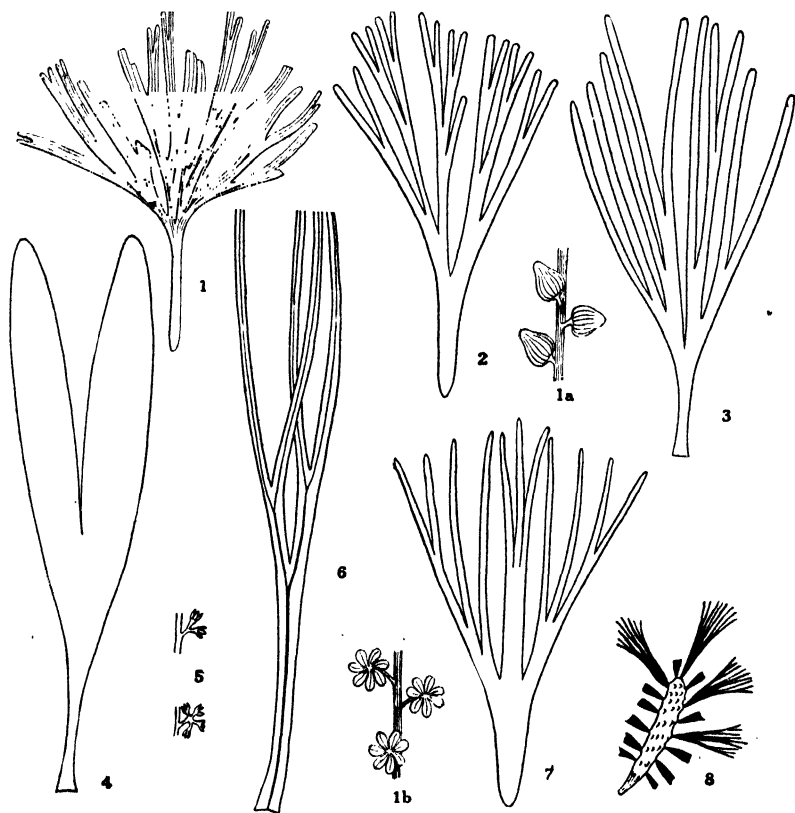


FIG. 22.—Views of different species of *Baiera*.

1. *Baiera muensteriana* Heer. Rhaetic of Balreuth (after Schenk):
 1. leaf.
 - 1a. unripe microsporophylls.
 - 1b. ripe microsporophylls.
2. *Baiera raymondi* Renault. Permian of France (after Zeiller).
3. *Baiera angustiloba* Heer. Jurassic of Siberia (after Heer).
4. *Baiera pulchella* Heer. Jurassic of Amur Land (after Heer).
5. *Baiera microsporophylls*. Upper Triassic of Switzerland (after Leuthardt).
6. *Baiera furcata* Heer. Upper Triassic of Switzerland (after Leuthardt).
7. *Baiera foliosa* Fontaine, $\times 5$. Lower Cretaceous of Virginia (after Berry).
8. Same, showing short shoot (after Berry).

in the Tertiary of Greenland, North America, Europe, and Asia, the characteristic *Ginkgo adiantoides* being abundant and scarcely distinguishable from the still existing species. The latter, long thought to be extinct except as preserved by cultivation in the temple gardens of China and Japan, has recently been reported in a wild state in

western China. The accompanying map (fig. 23) shows the area within which fossil *Ginkgos* have been found as well as the more restricted areas in Greenland, North America, Siberia, and Europe, where Tertiary representatives are known. The area in eastern Asia, included in a broken line, indicates the restricted natural habitat of the existing species, although it has been widely planted and thrives throughout the temperate zones, there being large numbers of magnificent trees in the Washington parks. Some representative fossils of both *Ginkgo* and *Baiera* are shown in the accompanying figures.

The order Gnetales includes but three existing genera, which differ widely in habit, habitat, anatomy, gametophytic structures, and in

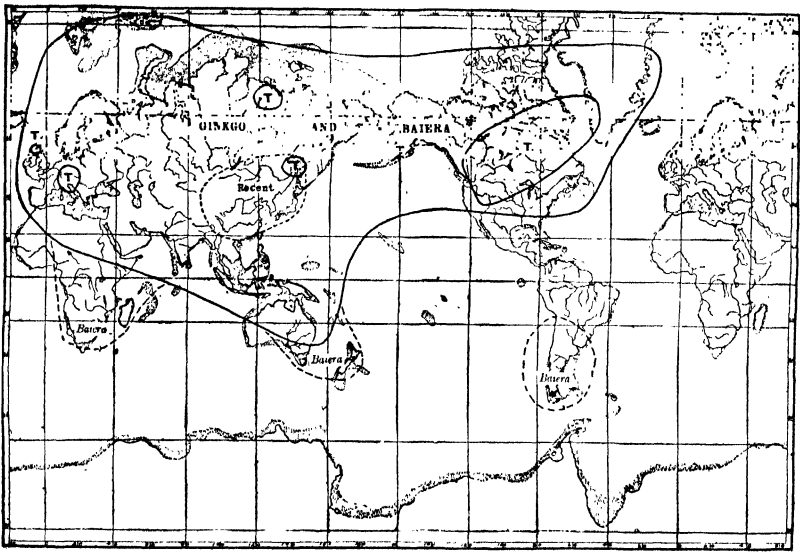


FIG. 23.—Sketch map illustrating the geologic history of *Ginkgo* and *Baiera*.

endosperm and embryo formation, and yet have a thread of common characters denoting their community of origin. *Ephedra*, with about 30 species of low, straggling shrubs with jointed ribbed stems and reduced leaves, inhabits the more arid parts of both the Eastern and Western Hemispheres. It is the least specialized of the three genera and more like the Coniferales. *Gnetum*, with about 26 species of both the eastern and western Tropics, comprises small trees or woody lianas with opposite, netted-veined, dicotyledonous-like leaves, and is most advanced in the direction of the angiosperms. The third genus, *Tumboa* (*Welwitschia*), is a remarkable monotypic form of western South Africa with a shortened, swollen axis and but two excessively long parallel veined leaves, and is obviously most specialized (aberrant). All of these modern forms are evidently the end products of

an ancient and diversified group which unfortunately has not been certainly recognized in the older fossil floras—*Gnetopsis* of the Carboniferous (Stephanian) of Europe and North America being, according to Oliver and Salisbury, a pteridosperm related to *Conostoma*. *Gnetum* has been definitely recognized in the Pliocene of Holland, while several species of *Ephedrites* have been recorded from the Jurassic, Cretaceous, and Tertiary. The relationship of these latter can not, however, be regarded as established beyond suspicion. Leaves suggestive of *Gnetum* are also present in the Lower Cretaceous of Virginia.

The chief point of interest in the Gnetales is their angiospermous characters shown in their possession of true vessels (absent in all other gymnosperms) in their broad rays, the presence of companion cells in the bast, the incipient perianth of the inflorescence, the floral morphology, the details of sporogenesis, fertilization, and embryogeny with the elimination of archegonia, the organization of eggs, and the dicotyledonous embryos. Such of these features as were known to the older morphologists suggested that the Gnetales were to be looked upon as representing the progenitors of the flowering plants and this view, which has long been in disrepute, has recently come into prominence again and is supported by a considerable body of evidence. Lang and Thompson have shown that the Gnetales are undoubtedly related to the rest of the gymnosperms and are not to be considered true angiosperms, as Lignier advocated. On the other hand, the attempt to consider them as a reduction series from the Mesozoic Cycadeoidales must be considered an abortive speculation. Some light on their geological history is greatly to be desired, since the most recent work with the existing forms indicates an ancient and collateral relationship with the balance of the Coniferophyta, going back possibly to the same pteridosperm plexus from which the Cordaitales took their origin. Hence, comparisons of the gnetalean flower with the fructifications of existing conifers is obviously futile. In the other direction, the least aberrant genus, *Gnetum*, while in no sense a "missing link," furnishes good grounds for considering as yet unknown group of gnetalean forms as the ancestors of the angiosperms through the primitive amentiferous families.

The members of the order Taxales are dioecious and they differ from all other Coniferophytes except the Ginkgoales and Gnetales, in that true cones are not organized, the ovules developing into seeds with a partially fleshy testa (aril) or cupule. Normally only a single ovule of the sporophyll reaches maturity in the modern forms, although more seem to have been developed in extinct genera like *Palissya*.

The Taxales contain but 8 of the 36 existing genera of the Coniferophytes and only about 75 of the 325 existing species. At

least two, and probably three lines of descent are obvious. The first of these is the stock of the family *Taxaceae*, which is regarded as primitive and a probable offshoot of the *Cordaiales* by some students, and is considered a modern reduction series by others. Whatever the intricacies of morphological legerdemain, it can be positively affirmed that the *Taxaceae* go back at least as far as the late Triassic and are hence more ancient than the ancestors assigned for them by nonpaleobotanical students. Moreover, the disconnected geographical distribution of the 17 existing species is a conclusive indication of an extended geological history, as is the greater geographical range of all of the genera in the past than they attain at the present time. The fossil record, in addition to occasional

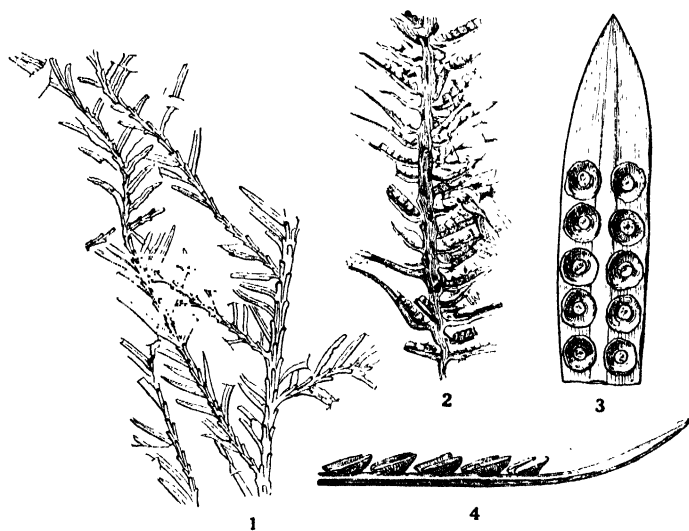


FIG. 24.—Foliage and fructification of *Palissya*.

1, 2. Twig and cone of *Palissya Braunii* Endl, from Rhaetic of Veitlahm near Culmbach, Bavaria.

3, 4. Cone scales of *P. sphenolepsis* Fr Braun in ventral (upper) and side view, showing seed cupules (after Nathorst).

species of *Taxus* (*Taxites*) and *Tumion* (*Torreya*) from the Cretaceous to the present, includes the Triassic genus *Palacotaxus*, the Lower Cretaceous genus *Cephalotaxites*, the Upper Cretaceous genus *Cephalotaxites*, *Cephalotaxospermum*, *Vesquia*, *Taxo-torreya*, etc. *Cephalotaxus* fruits have been found in the Pliocene of Europe and all of the other existing genera appear to have been well represented during Cenozoic times.

That the resemblance of *Cephalotaxus* to *Ginkgo* and of *Taxus* to *Cordaianthus*, the complex vascular anatomy of the seeds, the absence of resin canals, are not illusory features of the existing species is indicated by the foregoing brief survey of the fossil forms. The second line of descent in the *Taxales* is represented by the family

Podocarpaceae, often made to include two subfamilies, the Podocarpeae and the Phyllocladoideae, while some students consider the latter to represent a third evolutionary line.

The Podocarpaceae are to-day as distinctively characteristic of the Southern Hemisphere as the Taxaceae are of the Northern. They comprise over 50 of the 72 existing species of the order. Podocarpus is easily the dominant genus with over two score existing species, and is found on all the southern continents, where it

forms extensive stands comparable to those of *Pinus* in the North Temperate Zone.

The Phyllocladoideae are today confined to the Australian-New Zealand region but both subfamilies have an extended geological history. Probably their oldest authentic representative is *Palissya* (*Elatocladus*) of the Triassic and Jurassic, which had dimorphic foliage and remarkable lax cones made up of flat lanceolate foliar-like sporophylls, with two rows of small seeds in cupules on their upper (ventral) surface. *Palissya*, to which 10 or a dozen species have been referred, is abundantly represented by sterile twigs in the older Mesozoic of Europe, Asia, and America, as well as in both the Arctic and Antarctic regions.

Another equally old genus, of great interest but not completely known, is *Stachytaxus*,

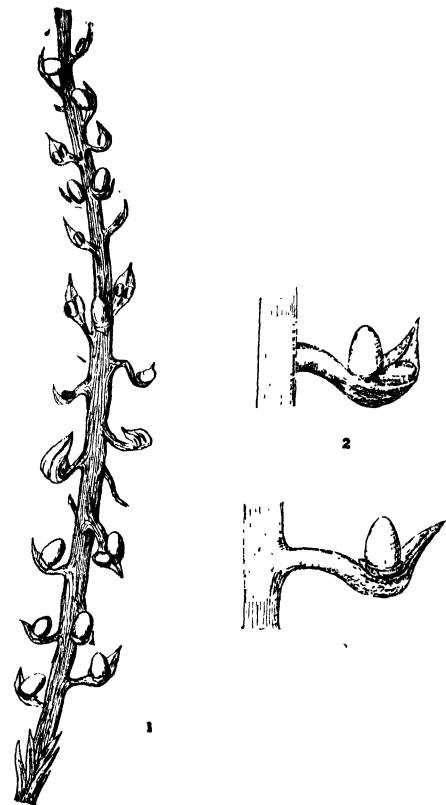


FIG. 25.—View of the fructifications of *Stachytaxus* (after Nathorst).

which has two or three species in the Rhaetic of Sweden and Greenland. It had yew-like leaves and loose cones, each sporophyll of which bore a pair of large seeds on their upper (ventral) face, which are compared by their discoverer (Nathorst) with the modern *Dacrydium*. *Podocarpus* itself contains about a score of fossil species which appear to have been abundant and rather widespread during the Tertiary, and are doubtfully recognized in the Upper Cretaceous. The allied genus *Nageiopsis*, represented in the modern flora by the *Nageia* section of *Podocarpus* with about a

dozen broad-leaved species ranging from Japan to the East Indies and New Caledonia, is exceedingly abundant in the Lower Cretaceous of North America, and is represented in the English Wealden and the Asiatic Neocomian. It has also been recorded from the English Jurassic and the Mesozoic of New Zealand.

Phyllocladus occurs throughout the Tertiary of Australia, and various supposedly related genera such as Phyllocladites of Spitzbergen and Protophyllocladus of North America and Asia are present in the Upper Cretaceous. Wood known as Phyllocladoxylon has been described from strata as old as the Jurassic.

The difficulty of correctly determining foliar specimens and the lack of structural fossil material of this order leave much to be desired in the knowledge of the geological history of the order, but such information as is available can not safely be ignored by weavers of phylogenetic hypotheses.

The ordinal rank of the Araucariales, first clearly emphasized by Seward and Ford, receives abundant confirmation from a consideration of their organization and geological history. The difficulties of homologizing their morphology with that of the Coniferales or Taxales has led to endless discussion and to the hypothesis, previously mentioned, of regarding them as independently derived from Lepidophytic ancestors. The existing forms, about fifteen in number, are segregated into the large-leaved genus *Dammara* (*Agathis*) with four or five species of the East Indian-New Zealand region, and *Araucaria* with ten or twelve species of South America and the Oriental region. They are dioecious and form large and complex cones in which the morphological distinction of leaf and bract is eliminated. The ovules are solitary and the pollen sacs are free and pendulous. Features of the vascular anatomy made much of by morphological speculators are the persistent leaf traces, the absence of resin canals, bars of Sanio, and wood parenchyma. The tracheids are characterized by crowded alternating and often flattened bordered pits, indistinguishable from those of the Cordaitales. Foliage leaves only are present, there being no traces of the scale leaves so characteristic of the Coniferales.

The existence of a variety of Mesozoic genera which combine some of the features of Araucarian vascular anatomy with Abietinaceous characters and the cone and foliar habits of a variety of genera (*Widdringtonites*, *Brachyphyllum*, *Raritanian*, *Thuites*, *Androvettia*, *Araucariopitys*, *Woodworthia*, etc.) has led some students to regard the Araucariales as derived by reduction from the Abietiniaceae, which are usually considered the most modern and specialized coniferophytes. This ingenious hypothesis entirely ignores the geological record, and the cone and foliar habits of the forms, here regarded as the more significant.

Only a summary of the geological history of the order can be given in the following paragraphs. Petrified wood from the Paleozoic can not be accepted as an indication of the presence of this order, since the wood anatomy is practically indistinguishable from that of the Cordaitales, hence the term *Araucarioxylon* may be of a dual significance. The Upper Carboniferous and Permian genus *Walchia* had foliage like that of the modern acicular-leaved *Araucaria*, bossed pith casts caused by the interlaced sclerenchyma fibers at the periphery of the pith, spirally-arranged leaf cushions, araucarian wood anatomy and single-seeded cone scales, and is commonly regarded as an early member of this order, as is also the Carboniferous genus *Schizodendron* (*Tylodendron*), and the Permian genera *Gomphostrobus* and *Ulmannia*. Permian leafy twigs have been referred to the genus *Araucarites* and various older Mesozoic genera, such as *Albertia* and *Pagiophyllum* probably belong in this alliance. Undoubted Araucarian wood and single-seeded cone scales are cosmopolitan during the Jurassic, and continue unabated throughout the Lower and Upper Cretaceous. *Dammara* foliage and cone scales likewise become cosmopolitan during the Upper Cretaceous, and extinct genera such as *Pseudoaraucaria*, with two seeded sporophylls, and *Protodammara*, with three seeded sporophylls, have also been described. The order appears to have continued its world-wide range well into the Tertiary for unquestionable araucarian remains of this age have been recorded from the New Siberian Islands north of Asia, North and South America, Europe, East India, on the border of the Antarctic. Africa, then as now, is without records. That the *Araucariales* began to dwindle in the late Tertiary and during the Pleistocene is shown by their absence at those times throughout the Northern Hemisphere, their presence on Kerguelen Island and in the Pleistocene of the Falkland Islands, and their subfossil occurrence beyond the present range of the existing species.

The *Coniferales* as here understood is an order coterminous with the family *Pinaceae* of the older botanists, and would possibly be more appropriately termed the *Pinales*. The details of structure and distribution belong more properly to recent botany, and such as are mentioned in the present connection will be introduced in the brief sketch of the three families into which the order is segregated. These are the *Taxodiaceae*, *Cupressaceae*, and *Abietineaceae*.

The family *Taxodiaceae* comprises 8 existing genera and about 13 existing species characterized by a nearly complete coalescence of bract and scale, wingless pollen, and spiral phyllotaxy. The extinct species greatly outnumber the existing, and the family has evidently passed its climacteric stage and seems destined to extinction. Moreover, none of the genera has more than three existing species (*Athrotaxis*), three have but two (*Sequoia*, *Taxodium*, *Glyptostrobus*),

and four have but one (*Sciadopitys*, *Cunninghamia*, *Taiwania*, *Cryptomeria*). Their restricted range is also an indication of former greatness. Thus *Glyptostrobus* is Chinese, *Sciadopitys* is Japanese, *Taiwania* is confined to Formosa, *Cunninghamia* and *Cryptomeria* are Chino-Japanese, *Athrotaxis* is Australian, *Sequoia* is confined to the Pacific and *Taxodium* to the Atlantic border of North America. The family is unrepresented in Europe, South America or Africa at the present time. Its fossil history constitutes one of the romances of paleobotany, illustrating the antiquity, growth to cosmopolitanism, and subsequent wane of the various types. The oldest known genus that appears to represent this family is the Permian and Triassic *Voltzia* with dimorphic distichous foliage, long, slender cylindrical cones of imbricated three to five-lobed sporophylls, and two or three-winged seeds. There are at least half a dozen species known and they are recorded from Europe, Asia, and South America, but not certainly from North America.

Another ancient and truly cosmopolitan genus was *Cheirolepis*, with distichous twigs, short pointed leaves and five-lobed two-seeded sporophylls. A genus of doubtful affinities is *Leptostrobus* of the Jurassic of Asia and North America, although *Sequoia* appears toward the end of that period (Portlandian). In the Lower Cretaceous the more noteworthy genera are *Sphenolepis* and *Athrotaxopsis*, although *Sequoia* is undoubtedly represented by foliage, cones and structure material at widely separated localities.

The Upper Cretaceous genera are *Geinitzia*, which may belong to the *Araucariales*; *Ceratostrobus* and *Microlepidium*, both European genera; *Cunninghamiostrobus*, a Japanese genus based upon structural cone material; *Cunninghamites*, which had numerous species in Greenland, Europe, and North America; and *Sequoia* which is abundant and recorded from all the continents except Africa and Australia, and from Spitzbergen on the north to Graham Land on the South. During the Cenozoic, especially during the older Tertiary, *Sequoia* continued unabated and is recorded from all the continents except Africa. *Athrotaxis* is recorded from Europe, *Cryptomeria* is found in Europe and the Arctic, while *Taxodium* and *Glyptostrobus* are found everywhere throughout the Northern Hemisphere in the greatest abundance, and both genera are still present in Europe as late as the early Pleistocene.

The most obvious characteristic of the family *Cupressaceae* is the cyclic arrangement of the reduced leaves, a feature which, acquired early in their history, has continued unchanged from the Cretaceous to the present. The cones are small and are hard or fleshy at maturity. The existing genera are nine in number and contain about 80 species, of which 40 per cent belong to the genus *Juniperus*. The

smaller genera show apparent anomalies of distribution coupled with an extended history.

There are a number of Mesozoic genera, of which *Brachyphyllum* (*Echinostrobus*) is the most prominent and including *Raritanian*, *Thuites*, *Androvettia*, and presumably *Moriconia* and *Inolepis*, which have been investigated anatomically and which show various combinations of the following features: Sclerotic pith, lateral pits of ray cells, branched leaf traces, mucilaginous resin canals, uniserial spaced bordered pits of the tracheids passing into alternating and sometimes mutually flattened series, transfusion tissue not lateral to the foliage strands, but showing a tendency to surround the phloem. These and other features are regarded in some quarters as indicating that these genera are descended from the *Abietineaceae* and should be included in the order *Araucariales*—a view that has received but slight acceptance and one that is dissented from in the present article.

The family history goes back to *Widdringtonites* of the Triassic, and to *Palaeocyparis* and *Brachyphyllum* of the Jurassic. These are not altogether conclusive in their testimony, but the family springs into unquestionable prominence during the Upper Cretaceous at which time in addition to *Brachyphyllum*, *Thuja*, *Thuites*, *Juniperus*, and disputed genera like *Androvettia*, *Moriconia*, and *Inolepis*, there were well marked species of *Widdringtonites* and *Frenclopsis* in which the foliar features are substantiated by fructification characters, which in the case of the valvular cones of the *Actinostrobinæ* are unmistakable. The genera *Callitris*, *Cupressus*, *Chamaecyparis*, and *Libocedrus* appeared in the Eocene, while many of the Cretaceous genera survived into that time and attained an extended range.

The family *Abietineaceae* is characterized by almost completely distinct bract and scale, by winged pollen, short shoots, needle leaves, and various recondite anatomical features of unproved phylogenetic import. They are admittedly the most complex morphologically, and are usually regarded as the most modern family of *Coniferophytes*, although some students consider them to represent the ancestral stock from which the *Araucariales*, *Taxales*, and the *Taxodiaceae* and *Cupressaceae* have been derived by reduction. Whichever view finally prevails, there can be no question but that in the light of present knowledge they have much the shortest geological history. There are 9 genera and about 125 existing species, of which more than half belong to the genus *Pinus*, and they form extensive forested areas in the North Temperate Zone, to which they are practically confined. Extinct genera are rare and include the Upper Cretaceous *Prepinus*, *Entomolepis*, and *Plutonia*. Among the still existing genera, *Pinus*

has numerous extinct species and goes back to the Lower Cretaceous (Pinites or Abietites), Cedrus goes back to the Lower Cretaceous, Picea and Abies to the dawn of the Upper Cretaceous, while Tsuga, Pseudotsuga, and Larix are exclusively Tertiary and Recent. The family is especially varied and widespread in the relatively short period from the Oligocene to the Recent.

PHYLUM ANGIOSPERMOPHYTES.

The taxonomy of the angiosperms is still in a most unsatisfactory state. The chief steps in their classification have been taken by Ray (1703), Jussieu (1789), De Candolle (1819), Endlicher (1836–1840), Brongniart (1843), Braun (1864), Bentham and Hooker (1862–1883), Eichler (1883), and Engler (1892). While very imperfect and founded to a too great degree upon floral morphology the classification proposed by Engler and derived largely from Eichler's work is the most satisfactory, and it has the additional advantage of having been elaborated in a general systematic treatise.

In contrasting the angiosperms with the coniferophytes or with any of the other great groups of seed plants, one is impressed with the lack of knowledge of both recent and fossil forms. Making their appearance in the geological record during the Lower Cretaceous, they soon outdistanced all competitors and from the Eocene to the present they have been the dominant plant group. Over 100,000 existing species are known, and the fossil forms, even in the relatively short period of their dominance, probably outnumber the recent, so that vast numbers of species and very imperfect knowledge render a generalized presentation well nigh impossible.

The angiosperms undoubtedly show the most perfect adjustment of the plant organism to a strictly terrestrial existence. Adaptable to a degree unequalled in other phyla they inhabit the most diversified environments, and some have secondarily invaded the sea margins as well as the lakes and streams, while others have become parasites, saprophytes, or epiphytes. The modification of their flowers for securing cross-pollination through the agencies of insects or birds is well known, as are the various modifications of fruits and seeds for dispersal by wind, mechanical ejection, floating, passing unharmed through the alimentary tract of birds or mammals, sticking or clinging to fur or feathers, etc. Ranging in size from tiny aquatics to giant trees several hundred feet tall, and ranging in their life span from that of a single season to several thousand years, they are the most impressive members of the vegetable kingdom. Fruits are confined almost exclusively to angiosperms and are apparently one of the effects of fertilization, as specializations for protection and dispersal of the seeds.

The variety of fruits is almost as great as that of flowers, and must be considered an important factor in the success of the angiosperms, as well as one of their prime benefits to humanity. It seems more than a coincidence that the evolution of a group of plants of the capacity of the angiosperms, in which, as in some of the cereals, 30 per cent of the total weight of the plant is stored as elaborated food in the seeds, should have been contemporaneous with the evolution of the warm-blooded animals. At any rate, it seems certain that human civilization could not have evolved but for the evolution of this plant phylum.

The angiosperms are so numerous and present so many morphological diversities that it is impossible to give a succinct characterization. Their outstanding feature is angiospermy itself, i. e., pollination results in bringing the pollen spores in contact with a receptive surface of the carpel (stigma), and not with the ovule, as in all other known seed plants. All known angiosperms have closed ovaries, and no other phyla have. At the same time it should be recalled that angiospermy was itself a product of evolution and that some time a series of fossil forms may be discovered showing this character in the formative stage.

Anatomically angiosperms are characterized, the dicotyledons normally and the monocotyledons primitively, by the vascular system of the stem constituting a tubular cylinder (siphonostele) of collateral bundles and having leaf gaps. The wood is marked by the presence of vessels arising through cell fusion—a feature common to the gnetalean coniferophytes and one absent in certain specialized families of angiosperms such as the Cactaceae and Crassulaceae, and in other possibly primitive families such as the Trochodendraceae. The improved conductive and supporting tissues of the angiosperms result in a general improvement in storage tissues and in a great expanse of foliage, and consequently a greatly increased production of nutritive materials. These histological features as well as the floral morphology, to be alluded to presently, are features of the sporophyte generation. The history of the male gametophyte does not differ materially from that which obtains in the various gymnosperm phyla; but the female gametophyte is not only more reduced, but its development is associated with new and peculiar features. Free nuclear division in the egg is wanting (a feature common to *Gnetum* and *Tumboa* among the Gnetales). The process of what is commonly called double fertilization is a strictly angiospermous characteristic. Among the units organized in the embryo sac is what is known as an endosperm nucleus. One sperm unites with the egg nucleus, and the result of this union is the embryo. The second sperm nucleus unites with the endosperm nucleus, and the result of this union is the trophophyte or endosperm which furnishes

the nutriment for the developing embryo and the subsequent germinating plantlet. This course of events is strikingly uniform throughout the phylum and is unknown in other plants.

Those who consider the formation of seeds as the most important characteristic of a definite group of vascular plants (Spermophyta) ignore the history of the origin of the seed habit, and the result is no more natural than the old Exogenous and Endogenous classes, or than one which attempted to use homosporry and heterosporry to define natural groups of the remaining vascular plants. Moreover, such a treatment is confronted with the necessity of defining a flower. If a flower is considered as a group of sporophylls in order to include the gymnosperms, it then includes many of the so-called flowerless plants. If, on the other hand, the gymnosperms are placed in their correct perspective and a flower is defined as a group of sporophylls associated with a perianth, the limit of the flower corresponds almost exactly with the limits of the phylum (except Gnetales) and the necessity, if such exists, for abandoning the convenient term flowering plants, as some students have advocated, is obviated. The popular concept of a flower is too firmly entrenched to warrant any attempt to arrive at a more philosophical morphology, and the fact that floral envelopes are lacking, either primitively or by reduction in some groups, is no more pertinent than the fact that some flowers consist entirely of floral envelopes and lack sporophylls.

The presence of floral leaves (calyx and corolla) surrounding the sporophylls and derived both from sterilized sporophylls above and bracts below, appears to have been conditioned largely by the habit of entomophily. Although the primitive floral envelopes were probably protective in their function, certainly their subsequent history and great diversity of detail are the result of entomophily. In the more primitive flowers the sporophylls tend to be free and the axis tends to be elongated with the members in a spiral arrangement. Evolution of the flower proceeded along the lines of reduction in axial length until the members passed to a cyclic arrangement when they tended to become definite and fewer in number and at length became confluent to a greater or less degree. The three marked stages are termed hypogynous, perigynous and epigynous, and all grades of intermediate stages are present. Inequalities of growth result in other diversities. The members tend to evolve from a radial symmetry (actinomorphic) to a bilateral symmetry (zygomorphic) or to an isobilateral symmetry with two planes of symmetry and with the halves unlike.

Systematists segregate angiosperms into two series—monocotyledons and dicotyledons—and there has been almost endless discussion as to which line was the more primitive. Both were present in the

Cretaceous, so that history fails to shed any light on the problem. Formerly, gymnosperms and other remains from the older rocks were thought to represent monocotyledons, but none such are now recognized. Modern opinion tends in the direction of regarding the distinctions between these two groups as largely cumulative, and that the number of the cotyledons and the correlative characters are of less phylogenetic importance than was formerly believed. The view is here advocated that the angiosperms are strictly monophyletic that the monocotyledons are not primitive, nor did the primitive angiosperms exhibit combined monocotyledonous and dicotyledonous characters, but that the dicotyledonous type is the more primitive, and that it has given rise to the monocotyledonous stock, not, however, as a single or monophyletic line of evolution, but by one such line combined with several reduction series derived from different regions in the dicotyledonous plexus. Systematists have long recognized the similarities between the monocotyledonous arums, pond weeds, and screw pines on the one hand, and the dicotyledonous peppers and willows on the other, as well as the convergence of certain Ranalian groups and the water plantains. The case of the water-lily family is a classic instance of a group of dicotyledonous origin which has essentially reached the monocotyledonous category.

Analogies between the amphisporangiate "flowers" of the aberrant Cycadeoideas of the Mesozoic and such dicotyledonous flowers as those of the Magnolia have furnished a basis for a theory of angiosperm descent which, while fascinating, is believed to be illusory. More definite evidence for a revival of the old view that the angiosperms are related to the gymnosperms through the amentiferous dicotyledons and some ancient gnetalean type similar to *Gnetum* has recently been accumulated. This evidence comprises the character of the inflorescence, the floral morphology, the details of sporogenesis, fertilization and embryogeny, the organization of vessels in the wood, the broad rays, companion cells in the bast, the habit and foliage, the dicotyledonous embryo, the elimination of archegonia and the organization of eggs. The foregoing considerations are derived entirely from a study of recent forms, since no certainly determined fossil forms of Gnetales are known, and no known fossil angiosperms throw any light upon these features.

The monocotyledons and dicotyledons may now be briefly characterized. In the former many of the forms are herbaceous, which argues for modernity. Anatomically the bundles are closed (amphivasal), are without cambium, and are scattered through the parenchymatous ground mass of the central cylinder. Sometimes the bundles indicate a primitively circular arrangement such as obtains in the dicotyledons, and the theory that a tubular central cylinder with foliar gaps was an ancestral condition accords with the view of

phylogeny here advocated. This does not mean, however, that the monocotyledons are strictly modern and monophyletic. The flowers tend to be trimerous and chalazogamy has not been observed. There is a greater reduction of sporogenous tissue in the megasporangium than in the dicotyledons. There is one seed leaf or cotyledon which is terminal in position, while the stem tip is lateral. The leaves are poorly differentiated into blade and stalk and tend to be entire, sheathing, and lack stipules. The venation is closed and the primary and lesser systems are so sharply contrasted that the leaves are commonly considered parallel veined, and even when the latter feature is less obvious as in the arums and many tropical forms, the contrast in caliber just mentioned remains obvious.

In the dicotyledons the stem shows a tubular cylinder (siphonostele) of collateral bundles, a persistent cambium forms secondary phloem and xylem, both of which elements arise through cell fusion. Secondary thickening results in a relatively larger display of assimilative tissue (foliage) and a branching habit. The cotyledons are two in number and lateral in position, and during germination the growing points and cotyledons are liberated by the elongation of the hypocotyl as contrasted with the monocotyledonous tendency to free the root and stem tip by the elongation of the cotyledon which functions as an absorbing organ suggestive of the "foot" of pteridophytes. The dicotyledonous flowers tend to be four or five merous. The leaves are well differentiated into petiole, blade, and frequently stipules are present. The venation is graduated and open and hence prevailing netted-veined, and this results in all degrees of lobation and division of the laminae.

Historically the oldest known angiosperms are found in the Lower Cretaceous of Greenland, North America, Europe, Australia, and New Zealand. These earliest known types do not appear to be primitive (only the foliage and secondary wood structures are known), and an extended earlier but unknown period of evolution seems to be demanded. By the close of the Upper Cretaceous, both monocotyledonous and dicotyledonous angiosperms are not uncommon, and these include palms and most of the principal families except the most specialized, such as the orchids among the former and the composites among the latter. A second modernization of the flowering plants took place at the dawn of the Tertiary and a third modernization in the Miocene. The Miocene floras were much like those of the present, but were richer in arborescent types and the forms were more widely distributed than they are at the present time. The bulk of the herbaceous vegetation appears to have been relatively modern in its evolution and those large groups or parts of groups that are especially characteristic of existing temperate floras, such as the Cruciferae, Borraginaceae, Labiatae, Compositae,

Umbelliferae, Krameriaceae, Papilionaceae, etc., were relatively very modern and their main evolutionary deployment seems to have been largely Pleistocene and postglacial. The subject is much too large for treatment in the present article, but a somewhat full discussion of the geological history of the angiosperms will be found in the Proceedings of the American Philosophical Society, volume 53, pages 129-250, 1914.

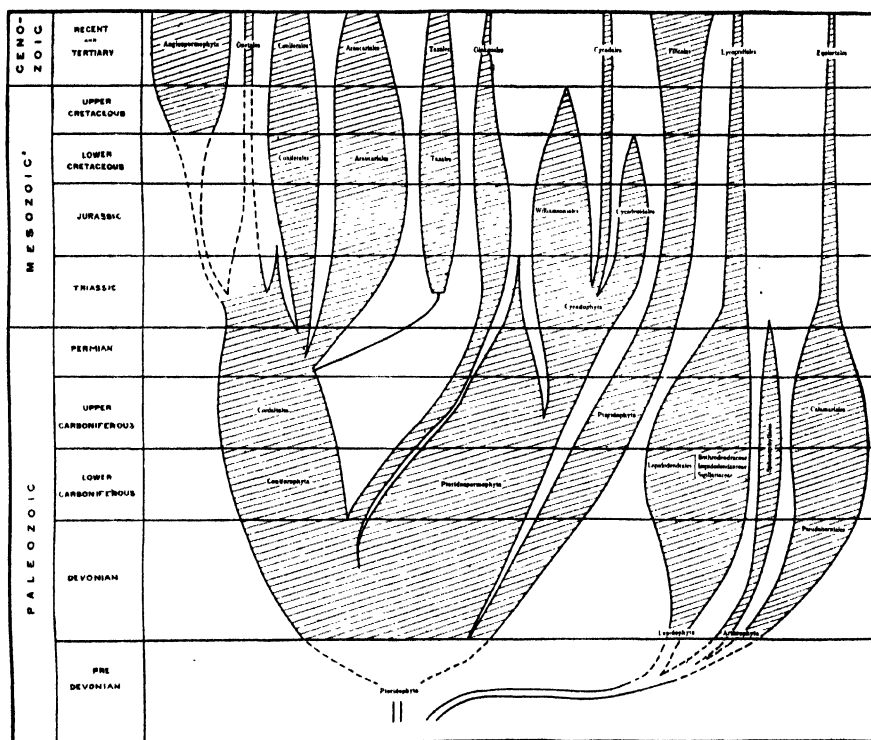


FIG. 26.—Diagram showing the geologic history and phylogeny of vascular plants.

CONCLUSION.

The mutual relationships of the various groups of vascular plants that have been briefly discussed in the preceding paragraphs are shown in figure 26, which aims to represent graphically their phylogeny as understood by the writer and their relative importance throughout geologic times.

THE EVOLUTION OF FLORAS.

STAGES OF PLANT EVOLUTION.

Somewhat as in human history a long period of mythology preceded written history, so in a consideration of the history of the

plant life on the earth the period of preserved records may be approached through a long antecedent vista of theoretic and more or less speculative conclusions, which, since plant life seems to have preceded the first distinctive animal life, reach back to the hypothetical origin of life itself. These stages may be somewhat arbitrarily considered as embracing first an Eophytic stage, followed by a Chlorophyllic stage, and the latter may be divided into an Algal substage, and a second or Pteridophytic substage comprising the origin and subsequent evolution of land plants.

The more important advances during the evolution of land plants have been the acquisition of secondary wood formation and the development of heterospory and the seed habit.

The marvelous recent discoveries in bacteriology have shown by what means the first life forms derived their nourishment through the utilization of inorganic materials. Bacteria are the simplest as well as the smallest of known organisms, and because of their minute size and similarities in form they are classified largely by the profound chemical reactions which they inaugurate. It is quite possible that they represent the first stage in the evolution of life upon the globe. At any rate they illustrate for us the manner in which, in a prechlorophyllic stage of plant history, simple organisms like bacteria derive their nitrogen from ammonia compounds and their energy by means of oxidizing catalyzers. All organisms which do not utilize organic carbon must have some source of energy that will enable them to take up carbon dioxide and partially replace the oxygen with hydrogen and thus build up complex organic compounds. The energy for this transformation is obtained by the oxidation of carbon, nitrogen, sulphur, or iron derived from hydrogen sulphide, ammonia, etc. These forms constitute the four primitive types of oxidizing bacteria that are known at the present time, and such forms which require no organic food materials are termed Prototrophic bacteria (nitrifying, nitrogen fixing, sulphur and iron oxidizing). Thus historically chemosynthesis must have preceded photosynthesis. Recent studies show that some form of photosynthesis by means of which certain bacteria utilize purple and other pigments in employing the infra-red rays of light probably preceded and may have been a step toward chlorophyll activities. The primitive bacteria have a **proteid** cell wall which is a modification of the general protoplasm, and not one of cellulose; they contain chromatin but do not organize a definite nucleus, and they multiply largely by vegetative fission. Systematists erect a phylum, the Schizophyta, to which they refer the Schizomycetes or bacteria, and the Cyanophyceae or the so-called blue-green algae. The latter are microscopic forms with a related organization, formerly considered as the ancestors of the bacteria, which were thus

regarded as simplified or degenerate types—a reversal of their true relationship.

The largely speculative conclusion sketched above derives a considerable measure of probability from the recent discovery of fossil bacteria, as well as evidences of their activities in some of the oldest sedimentary rocks, and it is legitimate to consider that the denudation of the most ancient rock surfaces was accelerated by the action of bacteria in facilitating rock weathering exactly as they have been shown to do at the present time. The next stage in bacterial history, represented at the present time by the Metatrophic forms, was that in which the necessary carbon for their activities was derived from the complex nitrogenous compounds of other bacteria, or of algae as the latter came into existence instead of from inorganic sources. The third stage was one in which the habit of true parasitism became developed, represented at the present time by the Paratrophic bacteria. The evolution of Metatrophic bacteria appears to have brought to a close that period of earth history during which the process of organizing complex organic molecules from inorganic materials was possible, since bacterial activity would inhibit such processes, and this explains in a measure why the origin of life was an evolution that could not take place in later geologic times.

Pre-Cambrian limestones, as well as those of later ages, which are without traces of discrete organisms, are now considered by geologists as indicating the presence of bacteria as the active agents of deposition, in the same manner as Drew and others have shown the recent calcareous oozes to have been precipitated. This also furnishes students with some measure of the probable temperatures of the waters. Similarly iron bacteria are probably responsible for the bedded iron ores of the primitive rocks.

The presence of Proterozoic bacteria has been demonstrated recently by Walcott. Paleozoic bacteria were first discovered by Van Tiegham in 1879, indicated by the evidences of butyric fermentation in the cellulose membranes of silicified plants from Saint Étienne. Subsequently a considerable number of Paleozoic bacteria were described by Renault and others by a microscopic study of sections of petrified plants and coprolites. Evidences of bacterial activity are obvious in petrified-plant material of all geological ages, but this field of study is not an especially fruitful one, since these organisms are so small, so ancient, and unchanging, and hence offer but few reliable characters of systematic value.

It might perhaps be legitimate to divide plant evolution into two major stages—the prechlorophyllic and the chlorophyllic—and to consider that the eophytic stage leading to the formation of the simpler algae required as long a time as all the subsequent evolution of the vegetable kingdom. When, however, it is recalled that the

whole protoplasm of these unicellular forms was virtually in contact with the environment the degree of potency of modifying forces must have been enormously greater than it was after the protoplasm was inclosed in a barrier of cellulose, or was rendered relatively inert by the formation of specialized systems of tissues. Thus these first stages of plant evolution may not have required the eons of time that at first thought seemed probable. During the Eophytic stage of evolution the hypothetical prechlorophyllic phase passed gradually into a second or chlorophyllic phase which may appropriately be termed the Algal phase of evolution. The original bacteria-like life forms obtained their energy from the geosphere and the hydrosphere. The formation of chlorophyll enabled them to make increasing use of the atmosphere as a source of energy. This development of chlorophyll, first as scattered granules and subsequently as definite plastids, so that the sun's rays were utilized for photosynthesis and the abstraction of carbon from the carbon dioxide of the atmosphere, was perhaps the greatest forward step in the evolution of life, second only in its importance to the origin of life itself. That this second phase of plant evolution was very ancient is shown by the traces of algae in the Pre-Cambrian rocks and by various collateral lines of evidence of plant activity, such as the vast amount of carbon (graphite) in the Proterozoic schists, the presence of opal silica due to algal activity, and the large amounts of bedded iron ore.

Nearest to the bacteria are the Cyanophyceae or blue-green algae. They are all tiny forms world-wide in their distribution, found in the intercellular spaces of higher plants, on bark, leaves, and roots, and forming, as the so-called gonidia, one of the two components of the lichen thallus. Their cell nucleus appears to lack a limiting membrane, their chlorophyll is not definitely organized into chloroplasts and they multiply entirely in a nonsexual way by fission. The primitive epicontinental seas probably swarmed with Cyanophyceae where the waters contained sufficient terrigenous sediments in suspension to furnish the needed nitrogen, phosphorus, etc. Where denitrifying bacteria rob the sea water of its nitrogen and precipitate calcareous ooze, algae are not common. The alga stock subsequently became diversified both in their vegetative and reproductive structures and processes for the various marine habitats, and have changed but little during the ages. It is among the more primitive of the Chlorophyceae or green algae, particularly the fresh-water forms that analogies point to the next great step in plant evolution, which was the invasion of the land. This finally resulted in the diversified vegetation of trees, fruits, and flowers as they exist at present. This third stage of plant history, which had its inception in pre-Devonian and probably in pre-Cambrian time, may appropriately be termed the Pteridophytic stage, and from these early pteridophytic stocks have

come not only the megaphyllous ferns, seed ferns, cycads, conifers, and flowering plants, but also the microphyllous lepidophytes and arthropytes, while the Bryophyta represent an independent and never thoroughly terrestrial line of evolution from other algal types, and are otherwise unrelated to the higher plants.

Summarizing the foregoing largely speculative evolutionary sketch, the history of the vegetable kingdom may be divided into a pre-chlorophyllic stage, the first chlorophyllic or algal stage and a second chlorophyllic or pteridophytic stage inaugurated by the beginnings of a land flora. The subsequent evolution of the various types of land plants from fern-like ancestors comprises stages of lesser magnitude and come more completely within the range of observation.

The most momentous event in the later history of the vegetable kingdom was the first occupation of the land. That we must look to the algae for the origin of land plants is clearly shown by the amphibious method of fertilization of all the so-called archegoniates. It was probably some of the simpler green algae (*Chlorophyceae*) that first left the water, somewhat as does the modern *Botrydium*. The necessity of a water supply resulted in water-absorbing organs (roots), and epidermal cuticularization to limit evaporation, and subsequently, to the evolution of mechanical tissue and conduction tissue to enable them to lift their assimilating organs above the surface. At first these primitive land plants were limited to moist environments and have been compared by Campbell with certain liverworts, as those of the class *Anthocerotes*, which he considers may represent in a general way the stock from which the mosses diverged in one direction and the ferns in another. Paleobotany furnishes no support for this specific view.

Formation of secondary wood by the various stocks of early land plants was a great advantage and far reaching in its results. Increase in diameter meant ability to reach a greater height and carry more branches, and thus display more foliage, and this meant many changes in habit and greatly increased working power. This may be summed up in greater mechanical strength, more assimilating tissue, and better conducting tissue.

Some lines, like the *Cordaitean*, evolved a regular arrangement with centrifugal additions like that perfected in modern trees. Other lines experimented with the old cryptogamic centripetal secondary wood. Others succeeded for a time in reaching a lofty stature with only a thin zone of secondary wood, relying mainly on the thick cortex for mechanical support. Such were the *Lepidodendrons*, but that their solution of the problem was incapable of survival by modification into something more efficient is proved by their failure to appreciably survive the Paleozoic.

Another early evolutionary advance was the origin of heterospory in the originally homosporous lines of descent. Reproduction by spores was, and still is, essentially an aquatic process, and hence dependent almost entirely upon external and uncontrollable conditions. By developing two kinds of spores the megaspores could be provided with a better chance of survival, while the microspores could be efficiently produced in much greater numbers, and thus render the chances of fertilization more favorable. The next step, approached through a series of forms that retained the megaspore for a gradually lengthening period, during which the parent plant furnished the needed nutriment and water and evolved an apparatus for facilitating the access of the sperm to the egg cell, leads naturally to the organization of true seeds, which was early approximated in such diverse stocks as the Lepidophytes and Pteridophytes, and perfected in the Pteridospermophytes. It is perhaps unnecessary to dwell on the advantages of the seed habit, the supremacy of its possessors in the later period of geological history, and at the present time, is conclusive evidence of the advantage it gives in the struggle for existence. It may be compared to the lengthening of the period of infancy, which is a factor of such importance in the most advanced human races, and seed and spore methods of reproduction may be compared with the viviparity of the higher mammals as contrasted with the oviparity of such animals as most of the fishes or the pelecypod mollusca.

The question of the origin of the characteristic alternation of generations is not directly a paleobotanical question. The absence of Bryophytes from the early floras and the general character of the oldest known land floras are entirely opposed to the derivation of the sporophyte from a sporogonium. The view that it was derived from a branched thallus has several supporters (Tansley, Lang). On the other hand, as Coulter forcibly puts it, there is no reason why an erect leafy axis bearing neither spores nor gametes is not quite as supposable as the appearance of a sporophore with neither gametes nor leaves, or a gametophore with neither spores nor leaves. On such a view, leaves would be primary structures—a view with much historical probability. Consequently the evolution of cones was sequential—a view in accordance with the older morphology.

PRE-DEVONIAN FLORAS.

Except for some very inconclusive objects, many doubtful, and a considerable number of well-authenticated algae (such as *Corematocladus*, *Chaetocladus*, *Callithamnopsis*, *Præmicorallina* from the Trenton limestone of New York and Wisconsin; *Nematophycus* and *Pachytheca* from America and Europe), no fossil plants are known from the pre-Devonian. The supposed Silurian flora described by Dawson and Matthew from New Brunswick, and that described by

Potonié from the Harz are now known to be Upper Carboniferous and Devonian, respectively. Nevertheless, the advanced character of the Devonian floras makes it a certain assumption that a somewhat similar flora existed during Silurian times. Floras are most fully preserved in continental deposits and these are the first to be destroyed during subsequent cycles of erosion, unless they happen to be deeply buried, and then they may never come to light in subsequent times. It is only from Devonian and later times that any considerable number of continental deposits have escaped this fate and are available for our enlightenment. Consequently, terrestrial floras appear upon the scene with apparent suddenness during the Devonian.

DEVONIAN FLORAS.

Such Devonian floras as are known—and their distribution includes Spitzbergen; Bear Island; the maritime Provinces of Canada; Maine, New York, Kentucky, and elsewhere in the United States; Russia, Norway, Scotland, Ireland, Bohemia, and Germany in Europe; and Australia in the Southern Hemisphere, as well as scattered localities of minor importance elsewhere—apparently indicate a cosmopolitan flora that was very like that of the succeeding Lower Carboniferous times. Many supposed fucoids have been described from Devonian rocks, but these are for the most part of a very indefinite nature. The gigantic stems of *Nematophycus* found in both the Silurian and Devonian are recorded from Canada, New York, Ohio, England, Wales, and Germany. Their structure is often preserved and they are indubitable algae, probably representing ancient and giant relatives of the modern Laminarians, which often grow to great size. A type exceedingly abundant and characteristic of the Middle Devonian of the Appalachian region was *Spirophyton*, which has often been considered as of mechanical origin, but which shows a carbonaceous spirally ascending thallus that passes through the bedding planes of the rock and probably represents an ancient seaweed comparable to a modern *Thalassophyllum*. Objects apparently representing the oogonia of Devonian charaphytes have been recorded from Ohio and elsewhere.

The ferns are represented in the Devonian by *Asterochlaena*, a genus of the family *Zygopteridae*, which ranged from the Devonian to the Permian; and by a considerable number of rather widespread genera of not very certain botanical position, such as *Sphenopteris*, *Sphenopteridium*, *Rhizopteris*, *Otidophyton*, *Dimeripteris*, *Spiropteris*, *Rhodea*, *Hostimella*, *Aneimites*, *Rhachiopteris*, etc. Certain similar but later forms have been shown to be pteridosperms, so that the status of many of these Devonian forms is rendered uncertain. A striking fern-like plant, conspicuous in the Devonian of

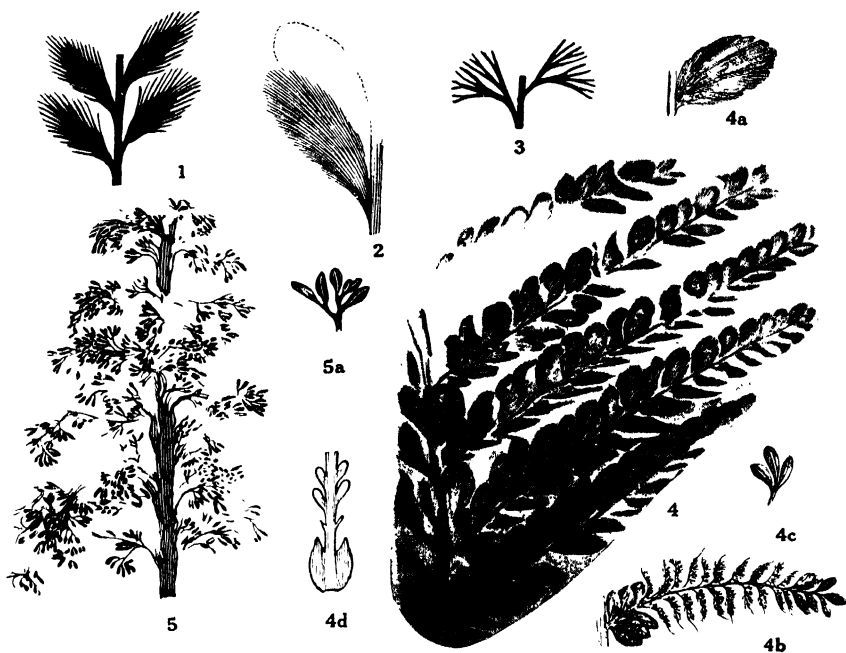


FIG. 27. —DEVONIAN FORMS OF ARCHAEOPTERIS.

1. *Archaeopteris fimbriata* Nathorst. Upper Devonian of Bear Island (after Nathorst).
2. *Archaeopteris jacksoni* Dawson. Devonian of Maine (after White).
3. *Archaeopteris fissilis* Nathorst. Devonian of Russia (after Nathorst).
4. *Archaeopteris hibernica* (Forbes). Devonian of Ireland (after Schimper).
- 4a. Pinnule of same (after Schimper).
- 4b. Fertile pinnules of same (after Schimper).
- 4c. Group of sporangia of same (after Schimper).
- 4d. Stipules of same (after Kidston).
5. *Archaeopteris hutchcocki* (Dawson). Devonian of Maine, fertile pinnules of type (after White).
- 5a. Group of sporangia of same (after White).

North America, Europe, the Arctic, and possibly present in China, is *Archaeopteris*. It includes a considerable number of species and appears to have survived into the Lower Carboniferous of Spain and elsewhere.

Archaeopteris shows considerable variation in the details of its organization. Its fronds were large, occasionally a meter in length, bipinnate with stipules at the base of the stipe. Sterile pinnules cuneate or obovate with entire or variously toothed or lacinate margins and dichotomously flabellate veins. The fertile pinnules borne on the same fronds with the sterile pinnules had their laminae greatly reduced and carried sessile or short-stalked large oval sporangia in groups of twos or threes. The latter are usually regarded as exannulate, and consequently *Archaeopteris* was formerly considered to have been a marattiaceous fern, although latterly, many students regard it as probably a pteridosperm. (Pl. 4.)

The Pteridosperms were also probably represented in the Devonian by the structural materials known as *Kalymma* petioles, and by the genera *Cladoxylon* and *Calamopitys* representing two different family types. The Lepidophyte phylum included Devonian species of *Lepidodendron*, *Leptophloeum* and *Lepidostrobus* and an abundance and variety of *Bothrodendraceae* referred to the genera *Porodendron* and the cosmopolitan *Bothrodendron*. An idea of their abundance may be surmised from the fact that the so-called paper coal of central Russia is made up largely of their stem cuticles. One of the most exceptional Devonian plants and the largest known pre-Carboniferous tree is *Protolopodendron primaevum*, which was found in the Portage beds near Naples, New York (fig. 28). The expanded butt shows that some secondary wood was probably formed. The roots are gone but *Stigmaria*-like rootlets, were preserved. At the base of the trunk the leaf scars are irregular. Above the base they are closely spaced on pronounced vertical ribs as in the *Favularia* type of *Sigillarias*. Higher up the ribs die out, the scars become rhomboidal, and bolsters appear until typically spirally arranged lepidodendron scars have replaced the *Sigillaria* type.

The leaves were persistent, about 3 cm. long, dilated at the base as in *Bothrodendron*, and lax or recurved. The leaf scars are on the most prominent part of the bolsters, oval in form, and show an upper or ligular scar, a central leaf trace scar, and on either side of the latter large lunate parachnoi. This remarkable type belongs to the group that includes similar forms often referred to the genus *Archaeosigillaria*, and represented in the Devonian, of New York, Pennsylvania, Norway, England, Bohemia, and Germany. Phylogenetically they appear to lie halfway between *Bothrodendron* and the *Rhytidolepis Sigillarias*. The genus *Psilophyton* which characterizes the Devonian of North America and Europe is very imperfectly known

and opinions differ regarding its affinities, some students considering that it represents a peculiar early Lepidophyte. Unquestionably a



FIG. 28.—*Protolpidodendron primaevum* (Rogers) of the Portage beds of New York.

good many unrecognizable fragments have been erroneously called *Psilophyton*.

The Devonian Arthrophytes included numerous primitive forms of *Calamites* known as *Archaeocalamites*. These are distinguished from the later *Calamites* by their unequal internodes, nonalternating ribs, and their dichotomously divided leaves. The imperfectly known order *Pseudoborniales*, with their lax cones and similarly compound leaves, belong here. Foliage indistinguishable from that of the later *Asterophyllites* and *Annularia* was present in the Devonian. *Sphenophyllum*—theoretically the most ancient Arthrophyte—was present in North America, Europe, and Bear Island, and the genus *Hyenia* from the Devonian of Norway is also supposed to have represented the *Sphenophyllales*.

The higher vascular plants of the phylum *Coniferophyta* were undoubtedly present during the Devonian, but so much of the material is made up of fragmentary impressions that great confusion prevails. Forms called *Psymphyllum* may represent either the *Ginkgoales*, *Cordaitales*, or be simply fern foliage. A *Ginkgophyllum* described from the Devonian of Ireland appears to be an early member of the *Ginkgo* stock. The *Cordaitales*, which were so prominent in the later Paleozoic, are represented in the Devonian by pith casts resembling *Artisia* and *Sternbergia*. This is not certain proof of the presence of true *Cordaite*s nor are the fragments from Devonian rocks referred to *Cordaite*s conclusive. The decisive evidence of the presence of *Cordaite*s or of closely allied forms belonging to this order, is furnished by the petrified woods from widely scattered Devonian localities referred to *Dadoxylon* or *Araucarioxylon*. A recently proposed genus, *Callixylon*, is based upon beautifully petrified wood of several species from the Middle and Upper Devonian of Ohio and Russia.

CARBONIFEROUS AND PERMIAN COSMOPOLITAN FLORAS.

• The Carboniferous rocks contain very many seams of coal, and in the Northern Hemisphere, at least, the Carboniferous is thought of as preeminently the period of coal formation. The enormous quantity of vegetable debris necessary for the formation of even a single coal bed has led to the belief that the vegetation of Carboniferous times was ranker and more luxuriant than at any other time in the earth's history, and that it grew in enormous swamps under torrid cloudy climatic conditions. Nothing is farther from the truth.

The vegetation of the Carboniferous was probably not more varied or luxuriant than at many other times in geological history, and it is doubtful if the palustrine forests of Carboniferous or Permian times were as dense, and they certainly contained much less of a variety than the existing tropical rain-forests or jungles, such as, for example, that of the Amazon basin. What makes the Carboniferous forests so interesting to the geologist quite aside from

the productive coal measures that resulted from their activities, is the widespread uniformity of physical conditions prevailing at that time, which facilitated the formation of coal.

Coal is found somewhere in the world in all geological periods subsequent to the Devonian, but scarcely anywhere or at any time was nature's balance so delicately adjusted that such a percentage of the contemporaneous vegetation escaped oxidation, accumulated over long periods, and was preserved. The impression that these coal swamps were like modern peat bogs, or that they covered thousands of square miles along the coasts of Appalachia is not borne out by the extent and lateral variation of the coal seams and associated sandstones and shales, and it is becoming increasingly clear that while favorable conditions prevailed over wide areas, individual seams are usually restricted in extent; some representing low coastal swamps, others valley swamps, and others lagoonal and lake deposits of drifted materials and a rain of spores and forest litter.

That the humidity was high and the sky cloudy is reasonable, but the evidence does not support the various theories that the sun was normally hidden or that the atmosphere was dense with carbonic acid gas. Nor was the heat torrid. That there was not the latitudinal or seasonal variation that exists to-day is shown by the cosmopolitanism of the floras and the normal absence of growth rings in the coniferous woods. It has been suggested that our knowledge of Carboniferous floras is confined to those which grew on lowlands adjacent to the regions of coal accumulation, and while this is true, it should be borne in mind that lowland and upland floras of any period differ merely in generic and specific types, and there is no reason to suppose that unknown orders or nascent phyla inhabited the Carboniferous uplands.

We may draw a generalized picture of a Carboniferous or Permian swamp as densely forested with clumps of slender, graceful Calamites—scouring rushes enlarged to fifty times the size of the modern ones—growing in and about the margins of the water; massive columnar Sigillarias with their persistent crown of needle-like leaves and their shallow, spreading roots; tall Lepidodendrons with their branched and evergreen crowns; lofty cordaites with their large pendent, evergreen leaves; large clumps of Marattiaceous and other ferns, slender-stemmed Sphenophyllums clambering over and among the other vegetation, and a variety of seed ferns everywhere—some with long, slender stems like Lyginopteris dependent on the jungle for support, while others with massive stems like Medullosa quite capable of taking care of themselves in the universal upward, light-seeking growth. (See fig. 14.)

Chronologically, many of the Devonian types lingered into the Lower Carboniferous, during which time Archaeopteris and Psilo-

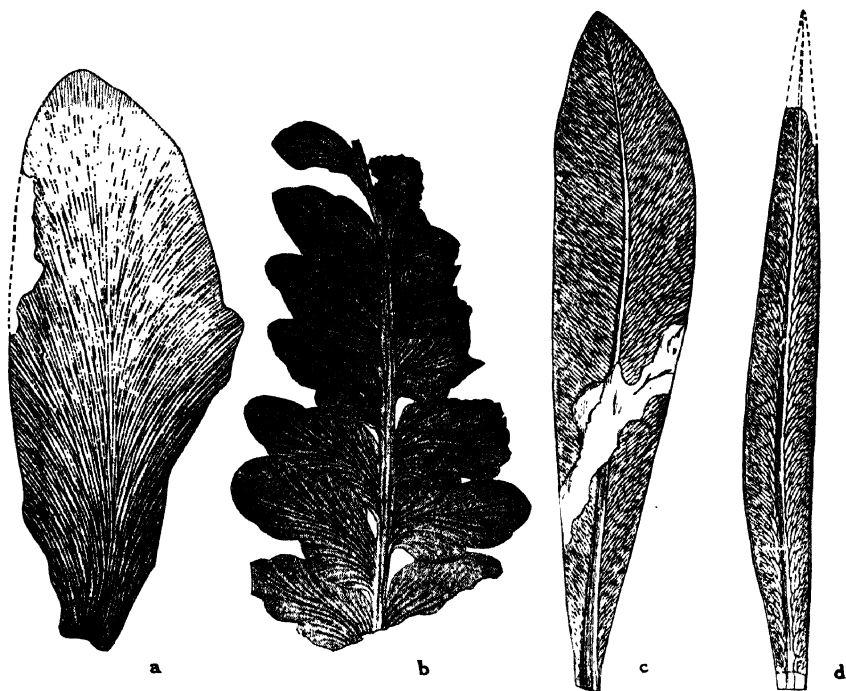


FIG. 29.—VIEWS OF TYPICAL MEMBERS OF THE GLOSSOPTERIS FLORA.

- a. *Gangamopteris cyclopteroides* Feistmantel.
- b. *Neuropteridium validum* Feistmantel, $\times \frac{5}{8}$.
- c. *Glossopteris indica* Schimper, $\times \frac{1}{2}$.
- d. *Glossopteris angustifolia* Brongniart.

phyton became extinct. The primitive Archaeocalamites were gradually replaced by the true Calamites. Protolcpidodendron and other Bothrodendraceae originated the distinct families of Sigillariaceae and Lepidodendraceae, and the seed ferns and true ferns showed a succession of forms that enables the paleobotanist to determine in just what part of the coal measures a particular florule belongs.

Throughout the Northern Hemisphere, and particularly in the Appalachian province as compared with Europe, relative uniformity of conditions lasted throughout the whole Carboniferous and into the Permian, and while there was a steady march of vegetation and a succession of varying forms, the general facies changed but little as compared with the contemporaneous history of the Southern Hemisphere (see *Glossopteris* flora). Already in the Carboniferous of both Europe and America, Cycadophyte fronds appear in the record, foreshadowing the great Mesozoic display of these plants. A few Ginkgo-like types were present and *Walchia* and *Voltzia* among the Coniferophytes give promise of the impending change from a sporophytic to a spermatophytic vegetational régime.

THE GLOSSOPTERIS-GANGAMOPTERIS FLORA.

At a horizon believed to be Lower Permian in age and associated with well-marked glacial deposits in Australia, Tasmania, India, South Africa, and South America, and with less definitive evidence of glaciation in several other areas, are found traces of a peculiar and regional flora in which the cosmopolitan types of the late Carboniferous and Permian, such as characterize the floras of these times in the Northern Hemisphere, are largely absent. This southern flora is termed the *Glossopteris* or the *Gangamopteris* flora from its two most characteristic elements. These were simple fern-like fronds, shaped like those of the common hart's-tongue (*Scolopendrium*), and were borne on creeping stems or rhizomes, long known by the name of *Vertebraria*. The fronds of both genera are much alike, of a similar lanceolate to obovate form and with an anastomosing venation. They are distinguished from one another by the presence of a thick midrib in *Glossopteris*, and by the practical absence of a midrib in *Gangamopteris*. In the former genus the sporangia are known and were borne upon very much reduced oval fronds. It is not certain whether they were true ferns or represent the seed ferns so common in the Paleozoic. Fronds of these two genera are shown, much reduced, in the accompanying figures (fig. 29).

Associated with these *Glossopteris* and *Gangamopteris* fronds were the remains of *Phyllothea* and *Schizoneura*, relatives of the northern *Calamites*, fronds of Cycadophytes (*Pterophyllum*, *Glossozamites*) and *Neuropteridium*, various fragments of ferns (*Cladophlebis*, *Pecopteris*, *Sphenopteris*, *Taeniopteris*), conifers (*Voltzia*),

and the leaves of *Noeggerathiopsis* and *Euryphyllum*, probably relatives of the northern *Cordaite*s. From the combined evidence of the organisms, their distribution, and the continental character of the deposits, geologists have restored from the depths of the present seas a vast southern continent extending from Australia to India and thence to Africa and South America, which is called Gondwana Land and which existed throughout the Permian and the first half of the Mesozoic. It was very probably connected southward from both Australia and South America with the land mass in the south polar region known as Antarctica, and a restricted land bridge connected it across northwestern Africa with southwestern Europe. Elsewhere along its northern borders a Mediterranean sea encircled the globe, separating Gondwana Land from Angara Land (the ancient continental mass of

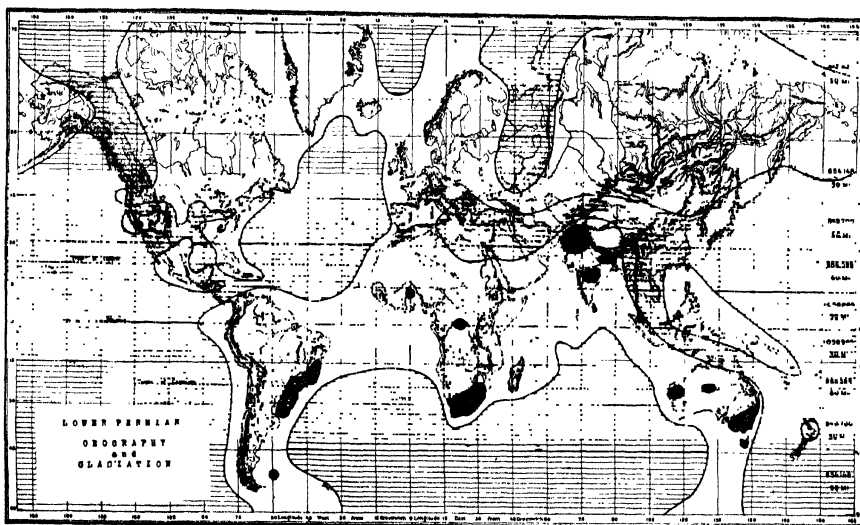


FIG. 30.—Sketch map showing the geography and glaciation of the Permian.

Asia) and from Eria (North America). It was upon this Gondwana continent or on the Antarctic continent to the southward that the *Glossopteris* flora had its inception.

It was the climatic changes resulting from this widespread emergence and elevation of the land and the consequent alteration of the oceanic and atmospheric circulation that furnished the stimulus for its evolution, and these climatic changes culminated in a glaciation that probably exceeded in its magnitude that of the more familiar and relatively recent Pleistocene Ice Age. These changes gradually banished the more characteristic elements of the cosmopolitan flora from this region, although it is known to have constituted the original vegetation of the country, having been discovered in Lower Carboniferous or in Devonian rocks in South America and Australia and

in the Tete basin in southeast Africa in rocks as young as the Upper Carboniferous (Stephanian).

The earlier *Glossopteris* floras immediately overlying the Glacial boulder beds, or in some cases, as in the Greta series of New South Wales, intercalated between glacial deposits, are everywhere relatively simple and unmixed and characterized by the plant types mentioned above. With changing conditions that can only be interpreted as an amelioration of the climate, various members of the northern cosmopolitan flora, especially the *Lepidophytes*, succeeded in reestablishing themselves. It is probable that they were never entirely extinct in the whole of Gondwana Land, but that they had been present throughout the Glacial period in northern Africa and northern South America.

This recolonization of the South by the cosmopolitan types is especially well illustrated in Brazil, where the farther the plant bed is above the basal boulder bed, the more cosmopolitan is the facies of the contained flora, which in the upper beds shows petrified gymnospermous wood lacking annual rings such as were typically developed in similar woods in beds immediately overlying the boulder beds in Australia. In India, which at that time was geographically difficult of access to returning northern types, no *Lepidodendrons*, *Sigillarias*, or true *Calamites* have been recognized, although a species of *Sphenophyllum* is recorded, and the genus *Noeggerathiopsis* may really represent the true *Cordaite*s. In South Africa the immigrants from the North included *Lepidodendron*, *Sigillaria*, *Bothrodendron*, and a doubtful *Sphenophyllum*. In South America they include *Lepidodendron*, *Lepidophlois*, *Sigillaria*, *Bothrodendron*, and the Paleozoic tree fern *Psaronius*.

Indicative of the Lower Permian age of the *Glossopteris* flora, as well as of a land connection to the northward, is the presence of *Glossopteris* and *Noeggerathiopsis* in the Upper Permian (Zechstein) of the Vologda and Petschora districts of northern Russia and in the Altai Mountains and elsewhere in Siberia, showing that these types spread northward from Gondwana Land into the region still occupied by the cosmopolitan flora before the close of the Paleozoic. The genus *Glossopteris* itself, as well as some of its associates, not including *Gangamopteris*, are known to have survived the Permian and were present as dwindling relics as late as the Upper Triassic (Rhaetian), or even in the Lower Jurassic, *Glossopteris* having been recorded from beds of Jurassic age (Liassic) in southern Mexico. *Glossopteris* has also been discovered in south latitude 85° in the Beacon sandstone series, which has been traced for over 700 miles across Antarctica, where it is coalbearing and probably of Permian age, although part of it may be younger. Other genera of the *Glossopteris* flora such as *Schizoneura* and *Neuropteridium* occur

in the Northern Triassic, and *Phyllothea*, which is not a typical member of the true *Glossopteris* flora, since it is found in the Carboniferous of Europe and Asia Minor (*Heraclea*), persisted into the Jurassic of Italy.

Some students interpret these facts of distribution as indicating that the Paleozoic cosmopolitan floras became extinct at or shortly after the close of that age and that Gondwana Land was the place of origin and the center of radiation of the Mesozoic floras, which, as regards those of the Northern Hemisphere, were hence of southern origin. There is but slight ground for this opinion, which will be referred to subsequently in the account of the Triassic flora. The only additional statement necessary in concluding this brief sketch of the *Glossopteris* flora is that during the Upper Triassic (Rhaetian) and the Jurassic, at which times the paleobotanical record again becomes reasonably complete, there is not the slightest trace of a northern and a southern floral province such as characterized the Permian, but from Greenland and Spitzbergen on the north to Graham Land on the south, and including Australia, India, Africa, and South America, the whole earth is once again clothed with a cosmopolitan flora as it had been in the Carboniferous, but one which, on the whole, was very different from the latter.

THE TRIASSIC FLORA.

The change in the terrestrial floras in passing from the Paleozoic to the Mesozoic is not as great as tradition holds; nevertheless, it is sufficiently marked. Older paleobotanists thought that the *Lepidodendrons*, *Sigillarias*, *Cordaites*, *Calamites*, and the characteristic ferns and seed ferns of the coal measures all became extinct by the end of Permian time. However, few if any of these types that gave the facies to the late Paleozoic floras, did not have some surviving relatives in the Triassic, and, moreover, many of the Paleozoic types were obviously on the wane during the Upper Permian, while new types, such as *Baiera*, *Ginkgo*, and some of the *Cycadophytes* (*Plagiozamites*, *Pterophyllum*, *Sphenozamites*), praenuncial of the Mesozoic, had already made their appearance.

One reason for the sharp contrast between the known Triassic floras and those of the later Paleozoic was the long interval, corresponding to the Bunter and Muschelkalk of European Triassic chronology, during which the character of the deposits was pre-vaillingly inimical for the preservation of vegetation (coarse aeolian or current bedded sands and saliferous salt pan sediments). It was not until the Upper Triassic (Newark formation of eastern North America, Lettenkohle and Rhaetian of Europe and the other continents) that fossil plants became abundant, and by that time

evolution had accomplished much. Moreover, there were special stimuli to change in the wide extent of continental areas, the formation of mountain ranges, the diversification of climates, and the competition of new plant associations that had resulted from the Permian glaciation. Furthermore, many geologists consider the prevailingly red deposits of the Triassic indicative of extremely arid if not real desert conditions. Without subscribing to this extreme view, it is probable from the geography of that time alone that the climates were less humid or uniform than they had been previous to the Permian glaciation; at least such was the case during the earlier Triassic.

Marine Triassic deposits of the Mediterranean regions attest to the abundance of calcareous algae (*Diplopora*, *Gyroporella*) at that time. On the land, mosses and hepatics were unknown and the floras consist overwhelmingly of ferns, Cycadophytes and Conifers. Among the ferns most of the Paleozoic types are missing or much reduced. The whole class *Coenopteridae* or *Primofilices* was absent. The class *Hydropteridae*, never abundant in the geological record, was sparingly represented in the late Triassic by *Sagenopteris*. The *Eusporangiate* ferns, so common in the Carboniferous and Permian, where they were represented by *Psaronius*, *Pecopteris*, etc., were



FIG. 31.—Restoration of *Macrotaeniopteris* (after Russell), $\times 1/10$.

the most prominent fern element during the Triassic, with seven or eight genera and a large number of species, especially in the Keuper and Rhaetian (*Danaeopsis*, *Taeniopteris*, *Macrotaeniopteris*, *Marattiopsis*, *Angiopteridium*, *Pseudodanaeopsis*, *Asterotheca*, *Oligocarpia*). *Macrotaeniopteris* with its large strict simple fronds was especially common in the rocks of the Newark formation in the eastern United States. The *Leptosporangiate* ferns, which comprise the bulk of the living ferns, were represented in the Triassic by the more ancient families, *Gleicheniaceae*, *Osmundaceae*, *Dipteriaceae*, and *Matoniaceae*, while *Cheiropteris* of the late Triassic is thought to represent the *Ophioglossales*.

Perhaps the most interesting Triassic fern family, and next to the Marattiaceae in importance at that time, was the Dipteriaceae. Surviving in only four species with a limited range from India to New Caledonia, they were represented during Triassic times by the genera *Protorhipis*, *Clathropteris*, *Dictyophyllum*, *Thaumatopteris*, *Camptopteris* (fig. 32), characterized by their dichotomous fronds,

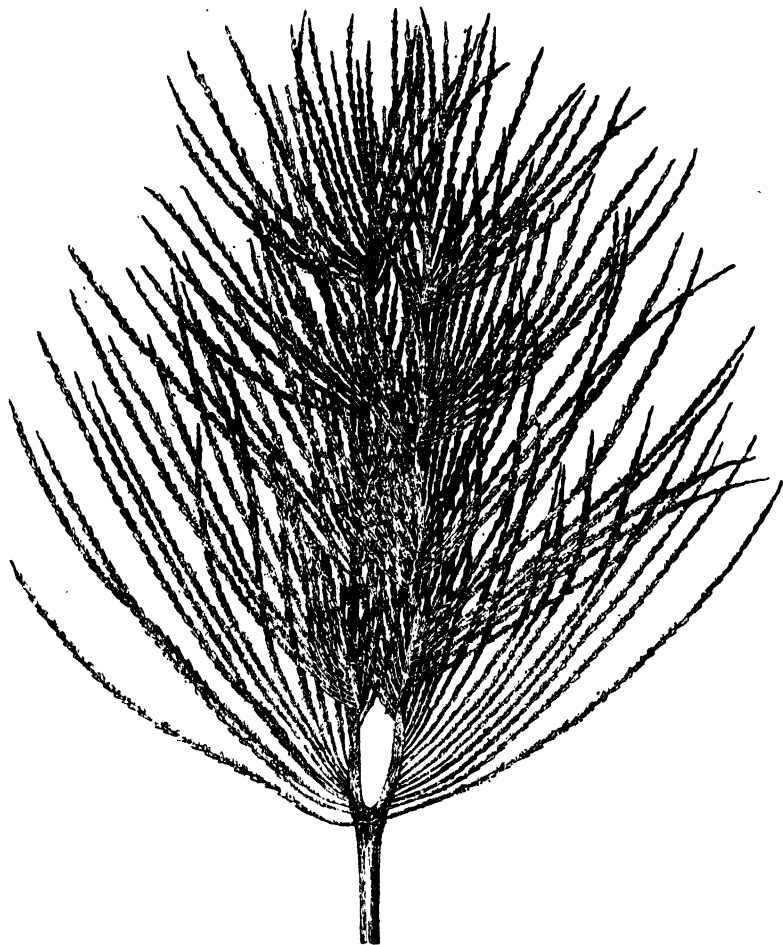


FIG. 32.—Restoration of *Camptopteris* (after Nathorst), $\times 1/4$.

indeterminate growth, and netted-veined pinnae suggestive of a leaf of a chestnut oak. These ferns were practically cosmopolitan during the late Triassic, especially in the two closely allied genera *Clathropteris* (fig. 34) and *Dictyophyllum* (fig. 33). *Protorhipis* did not attain its maximum range until later in the Mesozoic, while *Thaumatopteris* and *Camptopteris* were always more restricted in their range.

A fern-like genus, *Thinnfeldia*, of undetermined botanical affinity that appeared in the Rhaetian or uppermost Triassic in Australia, South Africa, South America, and Europe, is more especially characteristic of the cosmopolitan Jurassic floras.

The Arthrophyta of the Triassic were less varied than earlier. The order Sphenophyllales as well as the majority of the calamites had become extinct, but representatives of the latter continued to exist throughout the Triassic, where they were represented by *Schizoneura* and *Phyllothea* which survived from the Permian and by *Neocalamites* (fig. 35) which occurs in the Upper Triassic of Virginia, Mexico, Europe, Asia, South Africa, and Australia. In

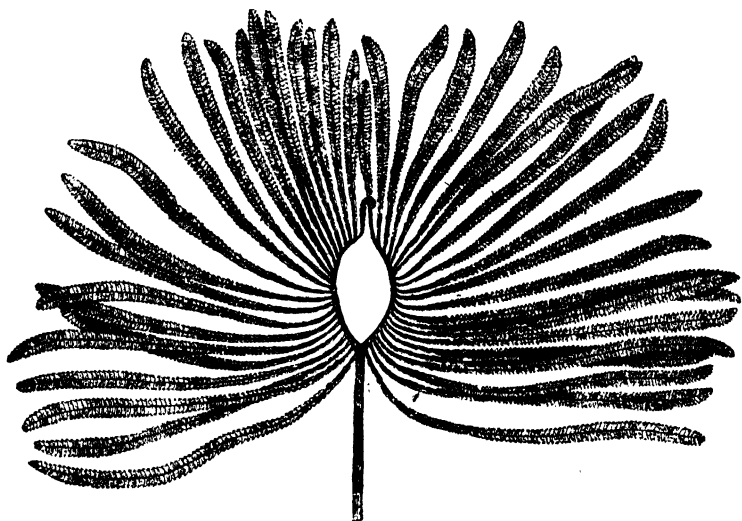


FIG. 33.—Restoration of *Dictyophyllum* (after Nathorst), $\times 1/2$.

addition to these, the remains of large species of *Equisetum* are common as stem casts in the continental deposits of the Triassic.

The Lepidophytes were represented during the Triassic by occasional fragments of *Lycopodites* (*Naiadites*) like foliage, and in the Lower Triassic by a few specimens of *Sigillaria* and a related genus known as *Pleuromeia*, which testify that this characteristic Permian type still lingered, although much reduced in importance. No lepidodendrons are known from the Triassic unless represented by the cone genus *Lycostrobus* from the Upper Triassic of Sweden. The Pteridosperms or seed ferns, so important and characteristic an element in Paleozoic floras had largely vanished. Triassic survivors probably existed although none are certainly known. *Glossopteris*, which gives its name to the Permian flora of Gondwana

Land, is found in the Triassic at a number of scattered localities and is thought to have been a pteridosperm.

The Cycadophytes, first recognizable in the Carboniferous, furnished one of the most prominent Triassic types of vegetation, represented chiefly by a great variety of frond impressions. Some of

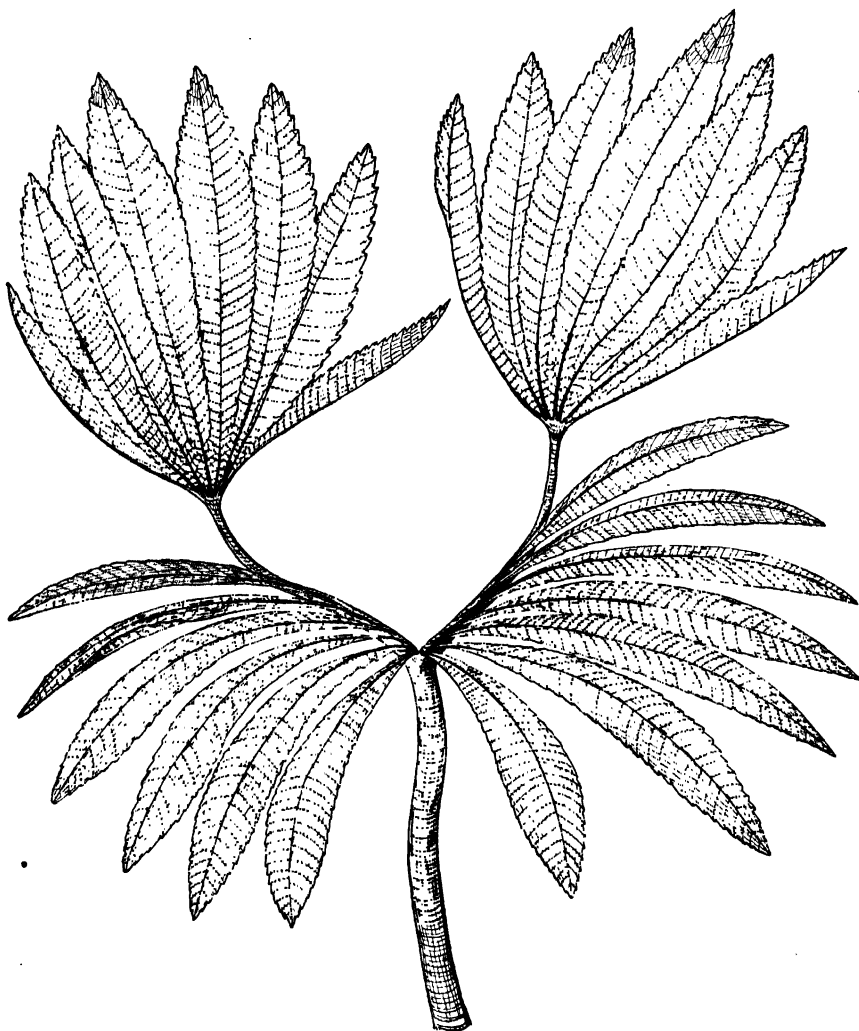


FIG. 31.—Restoration of *Clathropteris* (after Berry), $\times 1/2$.

the genera present at that time were *Pterophyllum*, *Ctenis*, *Anozamites*, *Ptilozamites*, *Otozamites*, *Sphenozamites*, and *Nilssonia*. The majority belonged to the slender branching-stemmed *Williamsonia* order, rather than to the squat forms like those of the Cretaceous *Cycadeoideas*, or the modern cycads.

The Triassic Coniferophytes represented all of the orders. The primitive Cordaitales of the Paleozoic were represented in the genus *Yuccites*, and by the surviving Gondwana Land genus *Noeggerathioipsis*. The Ginkgoales had two cosmopolitan types in the Triassic—*Baiera* and *Ginkgo*, both of which first appeared in the Permian or earlier, and both continued in abundance throughout the major portion of the Mesozoic. The Araucarian line was not as abundant as it became in the later Mesozoic, but appears to have been represented by *Albertia* of the European Lower Triassic, by *Pagiophyllum* which was common in North America and Europe; and by *Araucarites* and various petrified woods referred to the genus *Araucarioxylon*.

The Coniferalian group, often represented by ambiguous foliar shoots, comprises four families: Abietaceae, Taxaceae, Taxodiaceae and Cupressaceae. The first appears to be of Post-Triassic origin; the second was represented in the Triassic by the characteristic genus *Palissya* with dimorphic foliage and lax cones, and by the Upper Triassic genera, *Stachytaxus* and *Palacotaxus*; the Taxodiaceae were represented by the genus *Voltzia*, a survivor from the Permian, and probably by the genera *Cheirolepis* and *Sphenolepis*. *Widdringtonites* appear to have represented the Cupressaceae during the Triassic.

There are no known traces of Triassic flowering plants, despite the misleading names of some of the plants of that time, or the mistaken notions of the older paleobotanists that forms named *Yuccites*, *Convallarites*, etc., were monocotyledons. All of these supposed monocotyledons have been shown to be Cordaitæan, as in the case of *Yuc-*

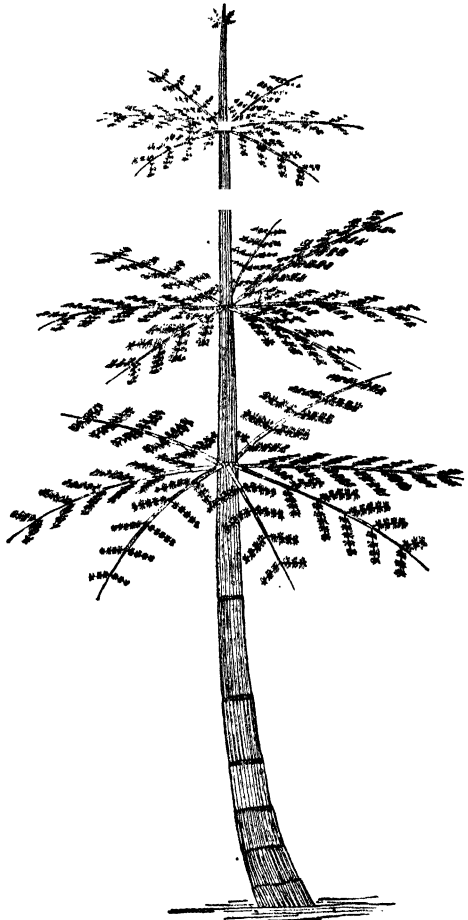


FIG. 35.—Restoration of *Neocalamites* (after Berry), $\times 1/18$.

cites, or Lepidophytic as in *Naiadita*, or Arthrophytic as in *Convallarites*.

Considering the march of vegetation during the Triassic as a whole it may be noted that succeeding the sparsely represented floras of the earlier Triassic, there appeared throughout the world during the Upper Triassic extensive floras which, while containing surviving stragglers from the Paleozoic, decidedly foreshadowed the cosmopolitan floras of the succeeding Jurassic time. Regarding the place of origin of these Triassic floras, it may be said that they contain a mixture of survivors from the northern cosmopolitan and the Gondwana Land Permian floras. The undue emphasis that has often been placed upon *Glossopteris* and the habit of speaking of *Schizoneura* and *Phyllothea* as members of the *Glossopteris* flora has led some students to consider that the Triassic flora was evolved in Gondwana Land. A careful analysis of the Triassic floras, however, for which space is lacking in the present article, clearly shows that this was not the case, but that the more prominent elements in the Triassic floras had northern ancestors, as, for example, *Voltzia*, *Pterophyllum*, *Baiera*, *Ginkgo*, *Sphenozamites*, *Phyllothea*, *Neocalamites*, etc., and originated in the northern land masses.

THE JURASSIC FLORAS.

The Jurassic was a time of warm climates, shallow seas on the margin of the continents, and low-lying lands. Its deposits are not sharply separated from the underlying Triassic or the overlying Lower Cretaceous, consequently, the contrast in the succession of floras are, in the main, the evolution of new specific types rather than of greater groups. Paleontologically the Jurassic is characterized primarily by the swarming marine faunas of its shallow seas. Following the almost world-wide occurrence of the rich palustrine Rhaetic floras of late Triassic age, the record consists of a succession of sandy, clayey, and calcareous rocks of marine origin, relatively poor in their representation of the contemporaneous terrestrial vegetation, although most of the Jurassic stages are fairly well represented by fossil plants in some part of the world.

Calcareous algae of both marine and fresh waters (charophytes) are not uncommon, but not especially noteworthy. Several modern appearing Hepatics have been recorded. Ferns, Cycadophytes and Conifera comprise the bulk of the vegetation. Many of these are generic types which ranged from the Triassic to the Lower Cretaceous. The magnificent lyre ferns (*Dipteriaceae*) of the Triassic survived in some of their manifestations in Jurassic times, as did some of the Triassic *Marattiaceae*. The former were not, however, so characteristic of Jurassic times as were the representatives (*Laccop-*

teris, Matonidium) of the family Matoniaceae, a family with but two existing Malayan species of Matonia.

There were several wide-ranging Jurassic species of Laccopteris and Matonidium, characterized by pedate fronds somewhat similar to those of the Dipteriaceae, but less variable or striking. The Gleicheniaceae were sparingly represented by species of Gleichenia; the Osmundaceae by Osmundites; the Schizaeaceae by Klukia; the Cyatheaceae by Dicksonites and Coniopteris; the Polypodiaceae by Cladophlebis, Onychiopsis, and Dryopterites; and the Hydropterales by various species of Sagenopteris. Probably the most characteristic Jurassic fern genera were Coniopteris, Laccopteris, and Thinnfeldia.

No Pteridospermophytes are known as late as the Jurassic, and it seems a reasonable assumption that this phylum had become extinct, although Glossopteris, a possible seed fern, is recorded from the Lias or basal Jurassic of southern Mexico. The Arthrophyte and Lepidophyte phyla, so prominent in the Paleozoic, had, by Jurassic times, come to be represented mainly by modern-looking species of Equisetum (Equisetites), Lycopodites, and Selaginellites.

Perhaps the most prominent element in Jurassic floras was the variety of ubiquitous genera of cycad-like fronds and fructifications. These are found from the Arctic to the Antarctic and on all of the continents at that time, and embrace a large number of form genera. The bulk of these belong to the order Williamsoniales, although Cycas-like fructifications are known (Cycadospadiæ). There is little evidence of the presence of the Cycadeoidales during the Jurassic, although their widespread occurrence in Lower Cretaceous times indicates that they were already in existence, as does the close approximation to their fructifications of those of Williamsonia. These have already been described in the paragraphs devoted to the Cycadophyta. Frond genera characteristic of Jurassic rocks, and often beautifully preserved as impressions, are Podozamites, Ptilozamites, Pseudoctenis, Ctenophyllum, Ctenis, Taeniopteris, Nilssonina, Anomozamites, Dictyozamites, Glossozamites, Otozamites, Pterophyllum, Ptilophyllum, and Zamites.

The remainder of the known Jurassic flora consisted of representatives of the Coniferophytes—the most advanced phylum, the Angiospermophyta, not being certainly known earlier than the Lower Cretaceous. Among the Coniferophytes, species of Ginkgo and of the allied genus Baiera were perhaps the most abundant and widespread. Jurassic Gnetales are not certainly known and the mainly Paleozoic Cordaitalean order appears to have already become extinct. The Araucariales were prominent throughout the Jurassic, in the deposits of which age, petrified wood, twigs, and single-seeded cone scales, essentially like those of the existing genus Araucaria, are found in abundance at widely scattered localities.

The Taxales are less clearly recognizable in collections of Jurassic plants, although their variety and abundance in the preceding late Triassic and in the succeeding Lower Cretaceous, gives certainty to the assumption of their presence through the intervening Jurassic. The order Coniferales, which includes the majority of the existing Coniferophytes, is well represented during the Jurassic, especially by members of the family Cupressaceae, to which *Brachyphyllum* (*Echinostrobus*), *Widdringtonites*, *Palaeocyparis*, *Cyparisidium*, and other genera, are referred.

The family Taxodiaceae is doubtfully represented by *Leptostrobus*, and *Sequoia* appears in the record before the close of the Jurassic. The relatively modern family Abietinaceae is of little importance until later times, and its presence during the Jurassic rests upon somewhat inconclusive remains of *Abietites* (*Pinites*), *Holochloris*, etc. Rather common Jurassic Coniferophytes of unknown botanical affinities are *Fieldenia* and *Phoenocopsis*, thought to be related to the Ginkgoales.

A picture of the flora at any time during the Jurassic would show nothing like the lofty forests of the Paleozoic or of Tertiary and modern times. The Jurassic floras, whether of swamp or upland, as known, consisted primarily of ferns, cycads, and conifers. The ferns were all forms of moderate size. None of the cycad-like forms, so characteristic of this age of earth history, were lofty; probably none were as tall as an old existing individual of *Cycas*, and the Jurassic cycads are more comparable in appearance to what is commonly denoted by the term "scrub." Rising above the general low level of this scrub were the various Coniferophytes, which may have predominated in more or less pure stands at certain localities, and among which the Jurassic representatives of the maidenhair tree (*Ginkgo*) stand out prominently.

THE LOWER CRETACEOUS FLORAS.

Lower Cretaceous plants are known from all of the continents except Antarctica, and they are particularly abundant in North America and Europe. The two most extensive floras are those of the Potomac group of Maryland and Virginia, and those of similar age from the opposite side of the Atlantic in southern Portugal. These afford valuable comparisons for shedding light on the place of origin and the migrations of the various types. A third large Lower Cretaceous flora is that of the so-called Wealden of England, Belgium and Germany. Other floras of this age are found in South Africa and eastern Asia, as well as in Spitzbergen, Australia, New Zealand, and Greenland.

While the known Lower Cretaceous floras necessarily represent but a small percentage of the species which clothed the earth dur-

ing that time, they furnish some data bearing on the march of vegetation during which flowering plants first appeared in the record and during which the transformation from a Jurassic to an Upper Cretaceous and essentially Cenozoic type occurred. This flora shows evidence in the varying proportions which the main types such as the ferns, Cycadophytes, and Conifers bear to one another, that there are represented plants that grew under local differences of soil, altitude, humidity, and precipitation conditions. It is apparent that the dominant types of the late Jurassic continued without marked change throughout the earlier Cretaceous. These were the ferns, Cycadophytes, and Conifers. Little is known of the Thallophyta, Bryophyta, ArthropHYta, or Lepidophyta.

The ArthropHYta, represented in the Lower Cretaceous by species of *Equisetum* had evidently dwindled to proportions strictly comparable to their present-day deployment. One or two *Selaginellites* represent the Lepidophytes and several *Marchantites* represent the Bryophyta. The more characteristic fern families of the older Mesozoic, such as the Marattiaceae, were greatly reduced in importance, and the families Schizaeaceae, Gleicheniaceae, Matoniaceae Osmundaceae and Dipteriaceae, which were prominent early in the Lower Cretaceous, were overshadowed by the Polypodiaceae before the close of the Cretaceous, the latter represented by various species of *Cladophlebis*¹ and *Onychiopsis*. Pteridosperms were unknown and it is reasonable to suppose that this phylum was no longer represented in the flora of the world.

Several interesting petrified Osmundaceae are known at this time, and the Gleicheniaceae were especially abundant in the far North along with other ferns indicative of great humidity. A peculiar tree fern represented by petrified fragments of large trunks and referred to the genus *Tempskya* was very widely distributed in North America and Europe at this time. A typical member of the Schizaeaceae was the genus *Schizaeopsis* found in the Potomac deposits of Virginia, with fertile fronds very similar to some of the modern tropical species of *Schizaea* (fig. 36). A survivor from the older Mesozoic was the Hydropteralean genus *Sagenopteris*, a handsome American species of which is shown in figure 37.

The Cycadophytes of the early Cretaceous were essentially the familiar, even if too little known types of the later Jurassic. They were abundant in genera species and individuals, and were quite as dominant an element of the Lower Cretaceous floras as they had been in the late Triassic and throughout the Jurassic. Before the close of the Lower Cretaceous, however, they became largely extinct. Some of the genera represented in the Lower Cretaceous were Dio-

¹ Some species of *Cladophlebis* appear to belong to the Osmundaceae. Those from the Potomac appear to represent the Polypodiaceae.

nites, *Stenopteris*, *Ctenopsis*, *Zamiopsis*, *Nilssonia*, *Dichotozamites*, *Podozamites*, *Glossozamites*, *Anomozamites*, *Cycadites*, *Otozamites*, *Zamites*, and *Pterophyllum*.

In addition the squat forms so common in a petrified condition at this time and represented by the genera *Cycadeoidea* and *Cycadella*, (the former of which has furnished so much information regarding the structure and morphology of the fructifications) are to be mentioned as important elements in the flora as well as the detached bract-encircled fructifications of the slender stemmed or *Williamsonia* forms. The *Ginkgoales* were represented by several species of *Ginkgo* and by numerous occurrences of *Baiera*, although neither genus is as common as it was earlier. The *Taxaceae* seems to have been more prominent

than later, with species of *Nageiopsis* and *Cephalotaxopsis*, both of which were individually abundant. The *Araucarian* conifers are well represented, but in no great variety. The *Abietinaceae* showed numerous forms of *Abietites* and before the end of the Lower Cretaceous, undoubted species of *Pinus* are known, and *Cedrus* has also been recorded.

Sequoia, *Sphenolepis*, and *Arthrotaxopsis* represented the *Taxodiaceae*, while *Frenelopsis* and *Widdringtonites*, which were widespread, represented the *Cupressaceae*. *Brachyphyllum* and

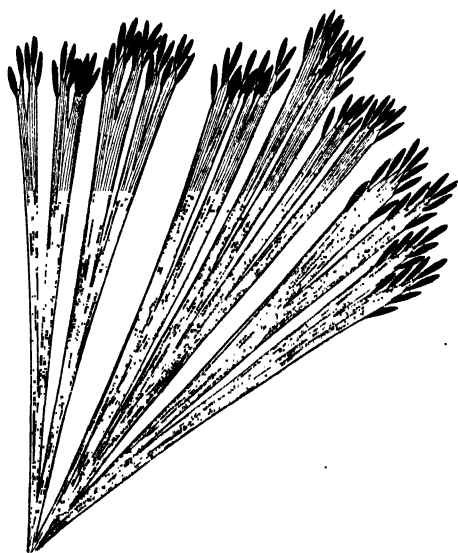


FIG. 36.—Restoration of a fertile frond of *Schizaeopsis* from the Lower Cretaceous (after Berry), $\times 4/5$.

Czekanowskia continued to survive. Little can be said about the Lower Cretaceous flowering plants. Certain genera from the oldest Potomac (*Rogersia*, *Ficophyllum*, *Proteaephyllum*) have been described as angiosperms, but they more likely represent Gnetalian forms comparable with the modern *Gnetum*. They are poorly preserved impressions and might even represent fragments of the fronds of *Dipteriacious* ferns—a conclusion amply proved for one of *Saporta's* proangiosperms (*Protorhipis*). This author has described a number of indefinite plant fragments from Portugal as *Poacites*, *Rhizocaulon*, etc., some of which he calls proangiosperms, while similar fragments are called monocotyledons. They are all entirely inconclusive. Nothing remotely suggestive of flowering plants is known

from the Wealden floras of England, Belgium or Germany; the similar floras from Japan, the Kootenai flora of Montana and British Columbia, or even from the Barremian flora of Russia, France, and England. The so-called Urganian flora of Greenland contains two or three dicotyledonous leaves, but there is some uncertainty regarding their exact age and they may be somewhat younger. Simi-

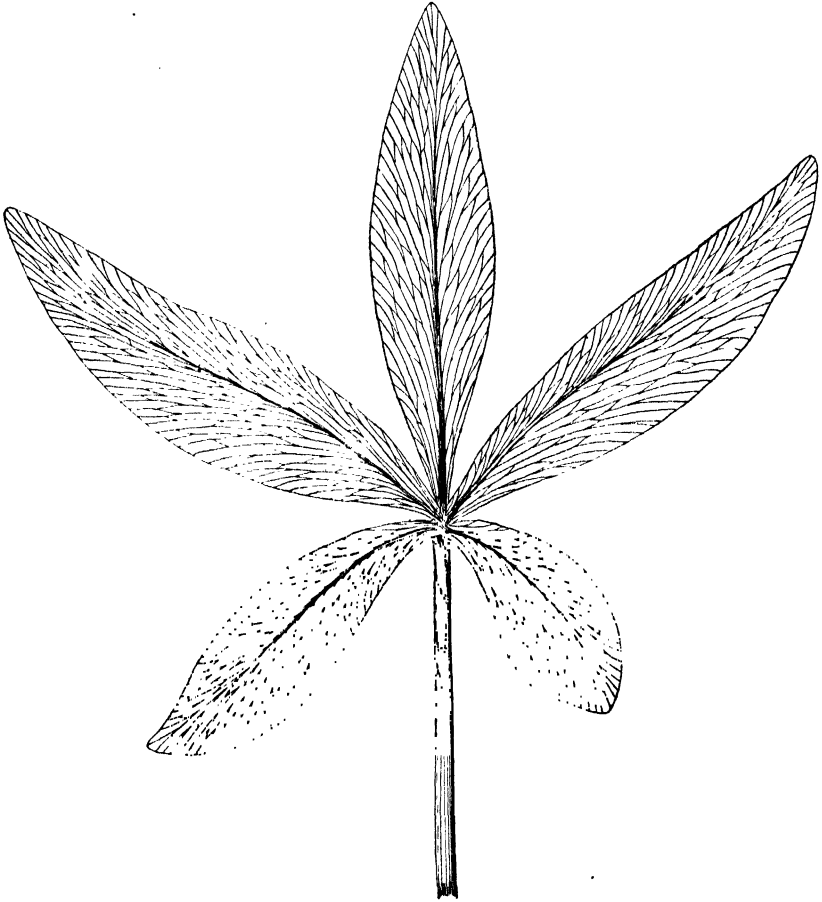


FIG. 37.—Restoration of *Sagenopteris elliptica* Fontaine, from the Lower Cretaceous of Virginia (after Berry).

ilar indefinite dicotyledonous remains have recently been recorded from Australia and New Zealand.

There is, however, satisfactory evidence of flowering plants in strata referred to the Aptian stage, based not only upon foliage but upon petrified wood, with structure preserved. Toward the close of the Lower Cretaceous in its uppermost stage (Albian), angiosperms become a considerable element in the flora, constituting 30 per cent of the uppermost Potomac (Patapsco) flora, 17 per cent of

the Fuson flora of the Black Hills, and over 35 per cent of the Albian flora of Portugal. It would be interesting to pursue the subject in more detail, to discuss the place and manner of origin of this latest and most highly organized plant phylum, as well as its early paths of migration, but the subject is highly speculative and may well await an increase of knowledge.

The same statement is in a measure true of attempts to describe Lower Cretaceous climatic conditions. The floras are so different from those of the present that any quantitative estimates are out of the question. These floras do, however, show such slight changes, which may be legitimately related to temperature conditions as they are traced from place to place, that a marked uniformity of temperature over many degrees of latitude must be admitted. From Peru, within 15° of the Equator to western Greenland in latitude 70° , or Spitzbergen in latitude 78° , the fossil plants indicate uniformity of temperature. It seems obvious from a consideration of the large fronded ferns and Cycadophytes that they could not have withstood a winter such as characterizes the cooler parts of the Temperate Zone at present, nor are deciduous forms known except *Laricopsis* and possibly *Zamites*.

THE UPPER CRETACEOUS FLORAS.

The Upper Cretaceous was a time of surpassing interest for students of floral history. Most of the survivors from the older Mesozoic that characterized even the later Lower Cretaceous were entirely absent or very much reduced in relative importance, while dicotyledonous leaves and palms appeared at that time in large numbers and great variety. The ancestry of a majority of our present forest trees can be traced back to the Upper Cretaceous, at which time their distribution and associates were very different. Upper Cretaceous plants are much alike wherever found and they are known from all of the continental land masses. Very many different species have been described, especially from North America, where they have been studied much more thoroughly than elsewhere.

Some of the largest and most interesting of the Upper Cretaceous floras are those of the Dakota sandstone—a littoral sand recording the transgression of a Cretaceous sea northward across the western interior of North America from Texas to the Arctic Ocean. The Dakota flora, described chiefly from Kansas and Nebraska, comprised several hundred species. It includes but a few Conifers—mainly forms of *Sequoia*; large numbers of ancestral hardwoods such as the earliest known birches (*Betulites*), many persimmons (*Diospyros*), beeches (*Fagus*), numerous figs (*Ficus*), *Magnolias*, Holly (*Ilex*), walnut (*Juglans*), tulip tree (*Liriodendron*), sassa-

fras, bayberry (*Myrica*), sycamore (*Platanus*), cottonwood (*Populus*), oak (*Quercus*), buckthorn (*Rhamnus*), willow (*Salix*), soapberry (*Sapindus*), sheepberry (*Viburnum*), etc. Associated with these familiar modern types were exotic elements, such as *Aralia*, camphor trees (*Cinnamomum*), *Cissites*, *Paliurus*; ancestral members of the orange family (*Citrophylum*); extinct genera, such as *Dewalquea*, *Aspidiophyllum*, and *Protophyllum*; tropical forms, such as *Oreodaphne*, *Zizyphus*, *Pterospermites*, *Sapotacites*, and *Sterculia*. A few doubtful leaflets represented the erstwhile abundant Cycadophytes of the older Mesozoic.

Another exceptionally interesting flora of about the same age as that of the Dakota sandstone is that found in western Greenland. Overlying the Lower Cretaceous Kome beds of Diskø Island and the Nugsuak Peninsula in latitude 69° to 72° north are several thousand feet of Upper Cretaceous and Tertiary deposits carrying fossil plants. Few regions within the Arctic Circle have been studied as thoroughly as this one. The fossil plants were first discovered about 100 years ago and excited the liveliest interest in European scientific circles, since the geologists of that time could not realize how different the climate is at the present time from what it was in Cretaceous and Tertiary times. The Upper Cretaceous plants of Greenland occur in an older (*Atane*) and a younger (*Patoot*) series. The former contains over 175 different plants, of which many are identical with forms found in central Europe (Bohemia, Moravia, Saxony) and in North America and Asia (Sachalin). Ferns were numerous, including many fine species of the genus *Gleichenia*. Associated with poplars, walnuts, magnolias, pines, oaks, ginkgos, and similar temperate types were bread fruit (*Artocarpus*), figs, cinnamons, and other tropical types. Many of these ranged southward along the Atlantic coast to Alabama and Texas, showing how uniform was the Upper Cretaceous climate. Very many plants of this age have been described from New Jersey, Maryland, the Carolinas, Alabama, and Texas. *Araucarias* and *Dammaras*, both confined to the Southern Hemisphere in existing floras, are common. The last *Baieras*, *Brachyphyllums*, *Williamsonias*, *Geinitzias*, *Frenelopsis*, and *Czekanowskia* occur at this time. Palms were abundant as far north as northern New Jersey, and there were many tropical, mixed with temperate, types.

There is not space to describe these ancient floras in detail nor to discuss the many interesting problems of distribution that they help to explain. Paleobotanists are agreed that the flowering plants (*Angiospermophyta*) must have had a long ancestry previous to their first-known occurrence in the rocks, because of the apparent suddenness of their appearance in great variety and with comparatively modern characters. There were many large land surfaces in

the earlier Mesozoic, about whose floras nothing is known, and these may have witnessed the evolution of the angiosperms. They certainly originated in one of the land masses of the Northern Hemisphere, and the evidence points to the vast expanse of Asia or the Arctic region as the theater of their earlier evolution. Certainly during the Upper Cretaceous there was a continuous spreading southward in Europe, North America, and Asia along land routes that are known from independent lines of evidence to have been in existence at that time, and almost everywhere the same forms occur, alike in Bohemia, Alabama, or Sachalin Island. They penetrated far into South America during the Upper Cretaceous (Argentina),

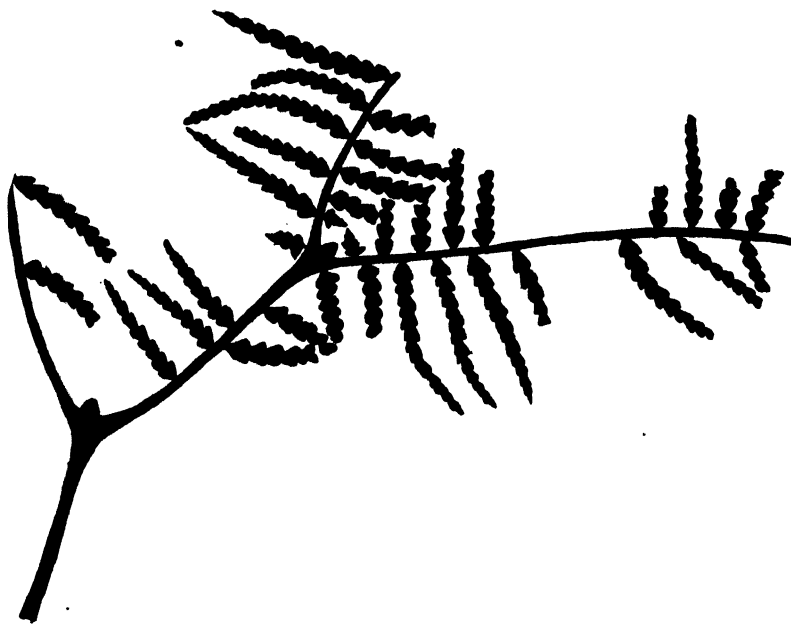


FIG. 38.—*Gleichenia pulchella* Knowlton, from the Upper Cretaceous of Wyoming (after Knowlton).

and even reached Antarctica (Graham Land). These Upper Cretaceous floras invariably show a mingling of temperate and tropical types indicative of a humid warm temperate climate, and they always contain forms like *Dammara*, *Araucaria*, *Widdringtonites*, *Proteaceae*, *Myrtaceae*, etc., that are to-day largely confined to antipodean regions. Throughout the Upper Cretaceous, new types continued to appear, while the stragglers from older floras gradually were dying out, so that by the dawn of the Tertiary most of the archaic forms had become extinct.¹

¹ A full account of the Upper Cretaceous floras of the world with lists of species and a complete bibliography is given by Berry in the volumes on the Upper Cretaceous published in 1916 by the Maryland Geological Survey.

THE TERTIARY FLORAS.

The classic chronologic subdivisions of the Tertiary are, from oldest to youngest: Eocene, Oligocene, Miocene, and Pliocene. These were based in the first instance largely on the percentage of living species of Mollusca in the rocks of the Paris basin, but subsequently received a lithologic and diastrophic basis. In some respects the Tertiary floras are more interesting than those that preceded them, since climates were genial, land surfaces ample, and the vegetation was exceedingly luxuriant and varied. Moreover, the key to the understanding of present-day geographical distribution is largely dependent on an understanding of these Tertiary floras.

Tertiary plant remains are exceedingly abundant and include those found in travertine, such as the rich Paleocene floras of Sézanne in France, those entombed in amber, especially the wonderfully preserved flowers in the lower Oligocene Baltic Amber. Buried swamp deposits preserved as lignite coals and the associated clays and shales are rich in plants, and such deposits are common throughout the world and have been particularly exploited in Europe and the western United States. Flood plain deposits with riverside plant types abound at certain horizons, and old lake beds yield a plentiful harvest. Two of the most celebrated lake deposits are those of the Miocene Lake of Oeningen on the Swiss border of Baden, made classic by Heer's researches, and the small Miocene lake of Florissant in the heart of the Colorado Rockies, where successive showers of volcanic ash entombed an extensive flora in the resulting fine-grained shales. Tertiary plants are also abundant in the far north in Alaska, Ellesmere Land, Greenland, Spitzbergen, and elsewhere, and they have also been found on Seymour Island on the margin of the Antarctic continent. Materials for the complete elucidation of Tertiary floral history are being rapidly accumulated, but only a few of the more striking incidents in this history can be mentioned in the compass of the present brief review.

An interval of emergence and land extension nearly everywhere intervened between the Upper Cretaceous and Tertiary sedimentation, in consequence of which and the time interval represented we find that the earliest Tertiary floras show marked contrast to the Cretaceous floras that had preceded them. In middle latitudes like that of the United States we find an extensive forest of hardwood trees, covering not only the east, but also the great prairie region of the West, since at that time there were no mountain ranges to shut off the moisture-laden winds from the Pacific. Abundance of moisture and luxuriance of vegetation are indicated by the abundant and extensive coal beds of early Tertiary age found in so many of the trans-

Mississippi States, as well as in the Southern States bordering the Gulf of Mexico.

This early Tertiary flora consisted of familiar hardwoods, such as willow, gum, cottonwood, sycamore, oak, walnut, hickory, etc., associated with figs and palms, and numerous exotic types, such as camphor, breadfruit, *sterculia*, *bauhinia*, etc., that have since become extinct on this continent but still survive in other regions. *Sequoia* still flourished as far east as Dakota and along the Mississippi Gulf, and its ferruginized cones are abundant at some Eocene horizons, while the clays contain profuse impressions of its foliage. At this time (Eocene) the Gulf of Mexico extended northward beyond the mouth of the Ohio and its shores were clothed with a wonderfully varied flora containing numerous migrants from the Tropics, such as breadfruit, custard apple, soapberry, rain tree, alligator pear, mangrove, fiddlewood, devilwood, persimmon, dilly, iron wood, mastic, buttonwood, stopper, buckthorn, wild lime, redbud, cocoa plum, sea grape, and many acacias and mimosas. Among these were forms like the Nipa Palm, distributed by ocean currents, and now confined to the littoral of southeastern Asia.

Engelhardtia is a tropical genus of trees belonging to the walnut family, but, unlike the walnuts and hickories, the seed part of the fruit has remained small, thus facilitating the production of a large number of seeds. The bracts, which are inconspicuous in the walnut, have become enormously enlarged in the *Engelhardtias*, so that each seed has three large wings to aid its dispersal. In our lower Eocene the oldest known representative of these trees shows the initial type of the winged fruits, so much more primitive than *Engelhardtia* that it is referred to a new genus named *Paraengelhardtia*. Associated with *Paraengelhardtia* are true *Engelhardtias*, also the oldest known, and both new to the Western Hemisphere. The modern forms number about a dozen, and all but one of these are confined to the Orient, where they range from the northwestern Himalayas through farther India and Burma to Java and the Philippines. One form, probably a descendant and relic of this abundant Eocene display in the Mississippi embayment region, is still found in the mountains of Costa Rica, and a considerable number are found in the upper Eocene and later Tertiary of central and southern Europe.

The winged fruits of *Engelhardtia* and its ancestor, *Paraengelhardtia* are shown in figure 39 (plate 6).

Among the leguminous trees, already mentioned as being very abundant, are numerous species of the coral bean, *Sophora*, evidently strand types, and one of these, which was exceedingly abundant in west Tennessee, is scarcely to be distinguished from the existing cosmopolitan strand plant of the Tropics, *Sophora tomentosa*.

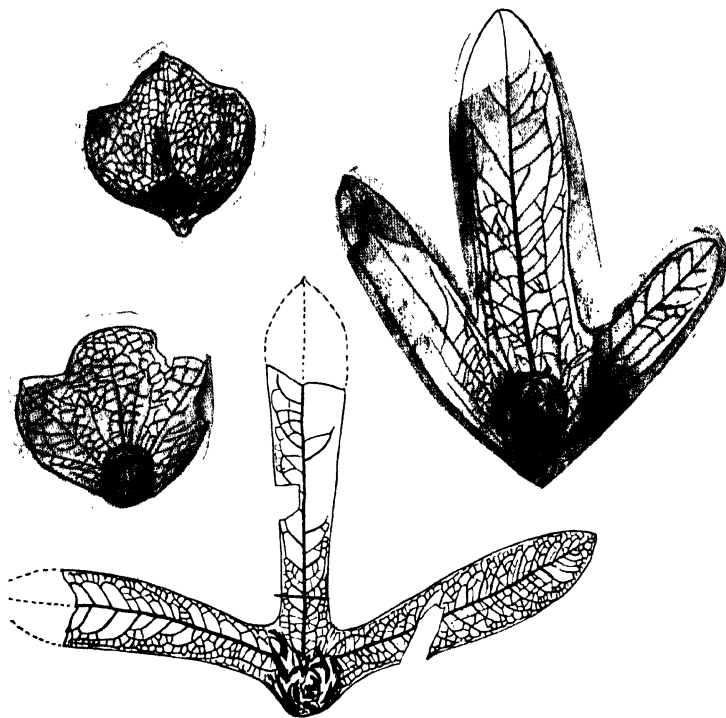


FIG. 39.—WINGED FRUITS OF *PARAENGELHARDTIA* AND *ENGELHARDTIA* FROM THE EOCENE OF THE MISSISSIPPI EMBAYMENT (AFTER BERRY), SLIGHTLY REDUCED.

Another genus belonging to this alliance, *Dalbergia*, to which the rosewood of commerce belongs, is represented by four species. The leaves of two of these combined with the characteristic one-seeded pods as they occur in the clays of western Tennessee are shown in the restoration, figure 40.

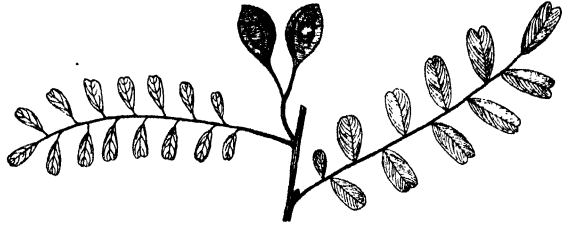


FIG. 40.—Restoration of lower Eocene *Dalbergias* from Tennessee (after Berry) much reduced.

One other genus of legume deserves special mention, since it has an abundance of fossil leaves and pods. This is the genus *Cassia*, to which the

senna, as well as our common herbaceous sensitive plants belong. The modern cassias range from herbs to trees and are very abundant and varied, between three and four hundred species having been described from the warmer temperate and tropical climes of all the continents. It is especially common in tropical America and had a



FIG. 41.—Restoration of a *Cassia* abundant in the lower Eocene of Mississippi and Tennessee (after Berry), $\times 1/2$.

long geological history extending back to the Upper Cretaceous. Over a dozen species have been brought to light in the Tertiary bordering the Gulf of Mexico, and a restoration of one of these from the lower Eocene, in which both the pods and leaflets were preserved, is shown in figure 41.

The genus *Paliurus* of the family *Rhamnaceae* (*Buckthorn*) is of

especial interest, not only because it is represented by the very characteristic fruits as well as by the leaves, but because it has such an extended geologic history and was formerly cosmopolitan. In the later Tertiary it dwindled, and in the existing flora it has only two species which are found from southern Europe through southern

Asia to China and Japan. Fossil forms are found as early as the Upper Cretaceous, at which time at least a dozen species, all North American, have been described, seemingly indicating an American origin for the genus. The leaves are not common in the lower Eocene but the characteristic peltate fruits are not rare, and the two combined have furnished the data for the restoration shown in figure 42.

Comparable floras are found in Europe in the Paris basin, along the south coast of England, and elsewhere.

With the passing of events the climate gradually became warmer, as attested not only by the terrestrial floras on both sides of the Atlantic, but by the contemporaneous marine faunas, until, during the upper Eocene and lower Oligocene, the climate of our Gulf tier of States and southern Europe became strictly tropical and was overrun by an appropriate tropical vegetation, while the temperate forest pushed into the polar regions until most, if not all of the lands within the Arctic Circle and part at least of the Antarctic continent, were forested by cool temperate types.



FIG. 42.—Restoration of *Paliurus* based upon fruits and leaves from the lower Eocene of Mississippi and Tennessee (after Berry), $\times 1/2$.

The most extensive of these polar floras is that recorded from western Greenland (latitude 73°), which included nearly 300 different species. Eighteen of these are ferns; 28 are conifers, including the Ginkgo, incense cedar, cypress, and numerous sequoias and pines; 21 are monocotys, including two palms; and a vast abundance of dicotyledonous leaves of willow, poplar, alder, hazel, beech, oak, elm, sycamore, walnut, ash, service berry, sumach, dogwood, gum, grape, magnolia, maple, holly, buckthorn, hawthorn, etc.

Traces of this flora are found in Grinnell Land, Spitzbergen, Iceland, Siberia, and elsewhere to within 8 or 10° of the North Pole, in a region that has since become a desert of snow and ice. In the

Southern United States at that time, one of the prominent features of the vegetation was the abundance of palms, represented by the impressions of leaves and much petrified wood. Among the palms are *Thrinax*, *Bactrites*, *Palmetto*; and a well-marked date palm is represented by characteristic seeds. Nutmegs are also represented by fruits, as are the *Copaiba* gum, the *Sapodilla*, and the *Carapa*. The leaves preserved include mangroves, satin wood, citrus, stopper, buttonwood, canna, sea grape, climbing ferns (*Lygodium*), and the tropical marsh fern (*Acrostichum*), cinnamon, and many other tropical types.

During the Oligocene the climate became cooler and drier. Many modern African and Australian types occur in Europe. In America the plains type of country became prominent in the west as a result of the rising mountain systems. The polar floras retreated to lower latitudes. Along the Gulf of Mexico many tropical types, such as the breadfruit and camphor survived, but were gradually replaced by temperate trees like the elm and hickory, until toward the close of the Miocene the flora became very similar to that of to-day, although the species were extinct forms of our familiar genera of mixed hardwoods which ranged farther west in the prairie States than they do at present, and exotic types like the *Ailanthus* at Florissant give testimony to the subsequent lapse of time.

The Miocene forests of Europe were extensive and contained a greater variety than do those of modern Europe. The floras of the Northern Hemisphere were still largely cosmopolitan, or at least Holarctic, and the Miocene and Pliocene deposits of Europe contain many American or Oriental types, such as walnuts, hickories, bald cypress, magnolia, tulip tree, sassafras, and sweet gum, which subsequently became extinct on that continent.

The Pliocene florally is simply a somewhat modernized Miocene. American Pliocene floras are little known, but include forms like the water chestnut (*Trapa*), now extinct in the Occident. In Europe the Pliocene was a time marked by the completion of the Alps and great geographical changes in the Mediterranean region, where the sea margins were densely forested with a great variety of mixed hardwoods, among which many American and Asiatic types were prominent. Numerous still existing species, such as the bald cypress, box, maple, yew, etc., appear during the Pliocene, plant bearing deposits of this age being especially common throughout Europe. In South America the tropical rain forests of the Amazon basin still covered the present desert region along the Pacific Coast, and the Andes were at least 14,000 feet lower than they are at the present time.

THE PLEISTOCENE FLORAS.

The Pleistocene, because of the widespread glaciation which gives it a distinctive place in geological chronology, is, for humanity, the Ice age or Glacial period, although a similar period of climatic rigor has already been described in connection with the Permian *Glossopteris* flora, and evidence of similar glaciations in the early Paleozoic and pre-Paleozoic times has been discovered in recent years. That the Pleistocene glaciation was contemporaneous with the evolution of the human stock and exercised a profoundly modifying influence on the noble races of mammals and forest trees of the Northern Hemisphere enhances its interest, as does the obviousness of its modification of the topography, resulting in numerous lakes, ponds, and bogs. The freshness of its moraines, boulder till, and sand plains—all scarcely modified in the few thousands of years that have elapsed since the last ice sheets disappeared—also emphasized its nearness to human history.

The inauguration of glacial conditions found an essentially similar flora in all three of the continents of the Northern Hemisphere. The retreat of the last ice sheet left an impoverished flora in Europe and two great asylums of survivors in eastern North America and eastern Asia. The explanation, broadly speaking, is most simple. Neither America nor Asia with their extensive coastal plains and north and south mountain chains offered insuperable barriers to migration southward and back, while in Europe the mountain ranges (Pyrenees, Alps, Carpathians, Balkans, Caucasus) all trend east and west, many were lofty enough to be local centers of glaciation, while the sea effectually stopped the gaps between the various mountain systems. Hence many of the plants of the Pliocene forests of Europe were unable to escape extinction and so perished.

There were at least four separate times when ice sheets accumulated over the land. Each of these lasted for from 10,000 to 20,000 years, and they were separated by long intervals of genial climate known as Interglacial periods, of thousands of years' duration, during which the floras spread northward to even beyond their present range. Many such Interglacial floras have been described from Europe, where the subject has been diligently investigated in connection with the economic study of peat bogs. The best known Interglacial flora of North America, where the extensive peat resources have been largely neglected, is that found in the Don Valley near Toronto. Here are found the plane tree, maple, osage orange, and other types that do not quite reach that latitude at present. Other traces of the Pleistocene floras are found in cave deposits associated with a partially extinct fauna, and buried swamp deposits overwhelmed by a mantle of sand during changes along the

coasts yield their quota of forms, most of which are still existing species, such as the bald cypress, loblolly pine, sycamore, Carolina poplar, hickory, river birch, and various species of oaks. All of these show that the Interglacial floras scarcely differed from those of to-day except in the details of distribution of the various species.

During the epochs of glaciation these temperate forests retired southward and gave way along the ice front to arctic willows and dwarf birches, which penetrated southward to about latitude 40°.

The post-glacial amelioration of the climate, the opening of areas that had been covered with glaciers to occupation, the mixing of soils through ice action, all combined to stimulate evolutionary activity in the plant kingdom, particularly among herbaceous forms, many of which date from this time. It seems probable that the characteristic Temperate Zone herbaceous families, already mentioned in the description of the angiosperms (ante) date from about this period.

Possibly more potent than natural causes in modifying the existing vegetation has been the action of humanity, with fire, ax, and domesticated grazing animals. Forests are now waning. Human intercourse results in untold feats of distribution, emphasized by the familiar cosmopolitan weeds of these modern days. Insect and fungal pests are similarly spread both rapidly and widely, and all of these factors tend to increasingly restrict or even exterminate the native vegetation.

THE DIRECT ACTION OF ENVIRONMENT AND EVOLUTION.¹

PRINCE KROPOTKIN.

There can be no doubt that species may become greatly modified through the direct action of environment. I have some excuse for not having formerly insisted more strongly on this head in my *Origin of Species*, as most of the best facts have been observed since its publication.—Darwin, *Life and Letters*, iii. 232.

When we cast a general glance upon the work accomplished during the last half century in connection with the theory of evolution, we see that the question which underlay most of the theoretical discussions and inspired most of the study of nature and experimental research was the great fundamental question as to the part played by the direct action of environment in the evolution of new species. This question was one of the absorbing thoughts of Darwin in the later years of his life, and it was one of the chief preoccupations amongst his followers.

A mass of researches having been made in this direction, I analyzed them in a series of articles published in this Review during the last seven years. Beginning with the evolution of the conceptions of Darwin himself and most evolutionists about natural selection,² I next gave an idea of the observations and experiments by which the modifying powers of a changing physical environment were established beyond doubt.³ Then I discussed the attempt made by Weismann to prove that these changes could not be inherited, and the failure of this attempt.⁴ And finally I examined the experiments that had been made to ascertain how far the changes produced by a modified environment are inherited.⁵ What we have to do now is to consider the conclusions which may be drawn from all these researches and discussions.

I.

When Darwin was leaving England for a cruise in the *Beagle* he was warned by one of his friends that he must not let himself be

¹ Reprinted by permission from *The Nineteenth Century and After*, January, 1919.

² *Nineteenth Century and After*, January, 1910.

³ "The Direct Action of Environment in Plants," July, 1910; and "The Response of Animals to their Environment," November and December, 1910.

⁴ "Inheritance of Acquired Characters: Theoretical Difficulties," March, 1912.

⁵ "Inherited Variations in Plants," October, 1914; and "Inherited Variations in Animals," November, 1915.

influenced by what he might see in nature in favor of the variability of the species. "None of these French theories," he was told (I quote from memory), which meant: "Nothing of the ideas of Buffon, Lamarck, and Geoffroy Saint-Hilaire, according to whom the direct action of the ever-changing conditions of life originated the infinite variety of vegetable and animal forms peopling the globe."

Darwin carefully observed nature and studied its life, and he felt the spell of "the French ideas." And both in 1842, when he wrote a first sketch of his conceptions about evolution,¹ and in 1859, when he published his *Origin of Species*, where he insisted upon the dominating part played in the evolution of new forms by natural selection, he indicated at the same time the part that is played by the Buffon-Lamarckian factor—the direct action of environment. Lyell even reproached him with the "Lamarckism" of the *Origin of Species*. However, at that time Darwin postponed a thorough discussion of the subject to a work on variation, for which he was collecting materials. Only nine years later he published the first part of this work; but in the meantime, already in the third edition of the *Origin of Species*, he felt bound to introduce important matter dealing with the direct action of environment. His great work on Variation, as well as the sixth edition of *Origin of Species*, contained, in fact, a straightforward recognition of the importance of the environment factor in the evolution of new species. He did not hesitate to admit that in certain cases "definite" and "cumulative" variation under the influence of environment could be so effective for originating new varieties and species adapted to the new environment, that the rôle of natural selection would be quite secondary in these cases.

The reasons for such a modification of opinion were acknowledged by Darwin himself. In the fifties there were no works dealing on a scientific basis with variation in nature; while experimental morphology, although it had been recommended already by Bacon,² was called into existence after the appearance of Darwin's work. Still, the new data, rapidly accumulated in these two branches of research after 1859, were such as to convince Darwin of the importance of the direct action of environment, and he frankly acknowledged it.

Of course he did not abandon the fundamental conception of his *Origin of Species*. He continued to maintain that a purely individual, accidental variation could supply natural selection with the

¹ The Foundations of the Origin of Species, a sketch written in 1842. Edited by his son Francis Darwin. Cambridge, 1909.

² In *Sylva Sylvarum* (Works, London, 1824, sec. 526) the great founder of inductive science wrote: "First, therefore, you must make account, that if you will have one plant change into another, you must have the nourishment overrule [the inherited dispositions]. * * * You shall do well, therefore, to take marsh herbs and plant them upon tops of hills and champaigns; and such plants as require much moisture, upon sandy and very dry grounds. * * * This is the first rule for transmutation of plants."

necessary materials for the evolution of new species. But he also had seriously pondered upon the following question that was raised by his first great work. Granting all that has been said about the importance of the struggle for existence—would natural selection be capable of increasing, or merely accentuating, from generation to generation a new useful feature, if this feature appeared accidentally, in a few individuals only, and was therefore submitted to the law of all accidental changes? Is it not necessary, for obtaining a gradual increase of the new character, that some external cause should be acting in a definite direction for a number of generations upon the majority of the individuals of a given group and its effects be transmitted more or less from one generation to the next?

The reply that Darwin gave to this question in 1868 in the revised (sixth) edition of his *Origin of Species* was pretty definitely in the affirmative. He wrote:

It should not, however, be overlooked that certain rather strongly marked variations, which no one would rank as mere individual variations, frequently recur, owing to a similar organization being similarly acted on—of which fact numerous instances could be given with our domestic productions. * * * There can also be no doubt that *the tendency to vary in the same manner has often been so strong that all individuals of the same species have been similarly modified without the aid of any form of selection.*¹

Besides, everyone who will take the trouble (or rather, give himself the pleasure) of rereading *Variation* will see that such a thing as an indefinite, haphazard variation, even with the aid of natural selection, hardly had any importance for the great founder of the theory of evolution at the time when he wrote this last work.² Over and over again he repeated in it that variability depended entirely upon the conditions of life; so that if the latter remained unaltered for several generations, "there would be no variability, and consequently no scope for the work of natural selection." And, on the other hand, where the same variation continually recurs, owing to "the action of some strongly predisposing cause," the appearance of new varieties is rendered possible, independently of natural selection. In chapter xxiii he gave the facts he was able to collect before 1868, "rendering it probable that climate, food, etc., have acted so definitely and powerfully on the organization of our domestic productions that new subvarieties or races have been thus formed without the selection by man or nature." It is also evident that if Darwin had had at his disposal the data we have now he would not have limited his conclusions to domesticated plants and animals. He would have been able to extend them to variation in free nature.

¹ *Origin of Species*, 6th edition, p. 72; the italics are mine.

² See *Variation in Domesticated Animals and Plants*, vol. II, pp. 289, 291, 300, 321, 322, 347, and so on, of the 1905 popular edition of Mr. Murray.

II.

For the first 20 or 30 years after the appearance of the *Origin of Species* research was chiefly directed to the study of the direct action of environment as it works in free nature and is made to work in our experiments. The chief result of these researches was to prove, first, that there are no such specific characters, either in plants or in animals, as could not be altered by modifying their physical conditions of life; and, second, that the variations obtained experimentally under certain conditions of heat or cold, dryness or moisture, rich or poor nutrition, and so on, were exactly those which are characteristic for animals and plants living in the Arctic and the Torrid Zone, in a dry and in a wet climate, in fertile prairies and in deserts. It was thus proved that if a species of plants or animals migrated from a warmer into a cooler region, or from the seacoast inland, or from a prairie land into a desert, variation itself amongst the new immigrants, apart from natural selection, would tend to create a variety representing an adaptation to the new conditions. The same would happen if the climate of a given locality underwent a change for some physiographical reason. In both cases natural selection would thus play a quite subordinate part—that of a “handmaid to variation,” as Hooker wrote in one of his letters to Darwin. It would have only to weed out the weaklings—those who would not possess the necessary plasticity for undergoing the necessary changes in their tissues, their organs, and (with animals) in their habits.

The researches of those years having shown how the floras and the faunas of the Arctic barren lands, the Alpine summits, the African swamps, the seacoasts, the deserts, and the steppes were adapted to withstand the climate and the general conditions of life in each of these surroundings, the first steps were also made, especially by botanists, to prove that most of these wonderful adaptations could be reproduced in a short time in our experiments. It was sufficient for that to rear the plants or the animals in those conditions of temperature, moisture, light, nourishment, and so on, which prevail in the different regions of the earth. Hence, already then, especially for those who were acquainted with nature itself, it appeared most improbable that the adaptations of plants and animals which we see in nature should be the results of merely accidental, fortuitous variations.

To take one of the simplest instances—we had learned from experiments that when a plant was grown under a glass bell in a very dry air its leaves soon ceased to develop succulent lobes, and the ribs of the leaves were turned into spines or prickles. And when we saw that spiny plants were characteristic of the vegetation of

dry regions, we could not be persuaded that the unavoidable transformation of leaves into prickles and spines in all plants immigrating into a desert, or growing in a gradually desiccating region, should count for nothing in the evolution of spiny species. We could not believe that all the evolution of the so-called "adaptive" structures in deserts, sea borders, Alpine regions, and so on, which is going on in nature on an immense scale as a physiological result of the conditions themselves, should leave no trace in the evolution of the desert, sea-border, and Alpine species; that the adjustments which are in the individual a direct consequence of the physico-chemical action of the environment upon its living matter, should have in the evolution of a species a merely accidental origin.

Already then many biologists took the Lamarckian point of view; and very soon Darwin himself, after having gained what he considered to be the main point of his teaching—the variability of species,¹ made the next step. He recognized the powers of the direct action of environment in the evolution of new varieties, and eventually new species. The part of natural selection in this case was to eliminate those individuals which were slow in acquiring the new adaptive features, and to keep a certain balance in the evolution of new characters. Its function was thus to give a certain stability to the new variety. Of course this stability did not mean immutability. There being no immutable species, it meant only that the new features would be retained for a certain number of generations, even if the new variety was placed once more in new surroundings, or was returned to the old ones.

III.

That changes produced in plants and animals by the direct action of a changing environment are inherited was not a matter of doubt for Darwin. He had carefully studied and sifted the experience of breeders and cultivators, and he found in it ample proofs of such an inheritance. He was aware, of course, that mutilations are not, and can not be, inherited as such (this had been known, in fact, since the eighteenth century); but he also knew that characters developed in a new environment were transmitted to the offspring—if the modifying cause had acted upon a certain number of generations. This last limitation was well known to both Lamarck and Darwin and repeatedly mentioned by them.

Having already discussed in a previous article the teachings of Weismann, who opposed this view, I shall refer the reader to that article² and only mention here and further develop one or two of its points.

¹ See his Letters.

² Nineteenth Century and After, March, 1912.

Going back to an early and not generally known work of Weismann, Upon the Final Causes of Transmutations,¹ I found that the origin of his teachings was not experimental; it was theological. In 1876 Weismann was still a Darwinist. His own experiments on seasonal dimorphism had confirmed the facts discovered by Dorfmeister concerning the effects of temperature in producing two different races of butterflies, while the experiments that Weismann made subsequently on mice to prove the nontransmission of a mutilation—the clipped tail—added absolutely nothing to our previous knowledge. If Weismann had taken the trouble of consulting Darwin's Variation before he had written his eighth essay he would have seen that clipped tails are not inherited, and he would have learned why such mutilations have little chance of being inherited—embryonal regeneration—and why their nontransmission did not affect Darwin's views upon the inheritance of variations.

It was under the influence of Schopenhauer's, Hartmann's, and Karl Baer's criticisms of the philosophical substance of Darwinism that Weismann accepted the idea of Baer that evolution without a teleological guidance from above was an unscientific conception. He thus came to the conclusion that, although evolution is a mechanical process, it must have been predetermined by a supreme power in accordance with a certain plan. And, in order "to reconcile teleology with mechanism," he borrowed from Nägeli and partly from Nussbaum the idea of "continuity" of the germ plasm; and thus he came to a Hegelian conception of an "immortal germ plasm"—"a matter endowed with an immortal soul." His hypothesis was thus suggested by those same considerations, lying outside the domain of science, that Darwin had had to combat.

In his Essays upon Heredity, written in 1881-1887, Weismann represented his germ-plasm hypothesis as an outcome of the remarkable microscopical discoveries made in those years by a number of well-known anatomists concerning the processes taking place during and immediately after the fertilization of the egg. But as early as 1897 Prof. Hartog made the quite correct remark that the cardinal defect of the theory of Weismann was its "objective baselessness."

It professes [he wrote] to be founded on the microscopic study of the changes in the nucleus in cell division, but there we find nothing to justify the assumption of two modes of nuclear division in the embryo—the one dividing the determinants and the other only distributing them between the daughter cells.²

Later on two of the leading microscopists who took part in the just-mentioned discoveries, far from giving support to Weismann's

¹ "Ueber die letzten Ursachen der Transmutationen," in Studien zur Descendenztheorie, Leipzig, 1876, chapter "Mechanismus und Teleologie." I don't know whether there exists an English translation of this chapter.

² "The Fundamental Principles of Heredity," in Natural Science, xi, October and November, 1897. Reproduced in Professor Marcus Hartog's Problems of Life and Reproduction, London, 1918.

contention that no material influences can be transmitted from the protoplasm of a cell to the germ plasm of its nucleus, distinctly contradicted it.¹

More than that. The fundamental point of all the hypotheses brought forward by Weismann was the isolation of the germ plasm and the impossibility of its being influenced by the changes going on in the body under the influence of the outer agencies. But the more we advanced in the study of heredity the more we were brought to realize the close interdependence of all the organs and tissues of the living beings—plants and animals alike—and the impossibility of one of their organs being affected without a disturbance being produced in all parts of the organism.² We learned from the best embryologists that the living substance which is the bearer of inheritance is not localized in the nucleus of the germ cells, and that an intercourse of substances between the nucleus and the cell plasm must be taken as proved.³ Finally, we have now experiments tending to prove that even unimportant lesions of the body may be followed by important modifications in the reproductive cells.⁴

The difficulties which the hypothesis too hastily framed by Weismann had to contend with when it was confronted with the scientific observation of nature, and the new hypotheses he brought forward to meet the rapidly accumulated contradictory facts, were discussed in my above-mentioned article. Sufficient to say here that, after having emphatically denied at the outset that his "immortal" germ plasm could be influenced by external agencies "in the same direction as that taken by the somatogenic changes (in the body) which follow the same causes";⁵ and after having maintained that the mixture of two germ plasms in sexual reproduction (that is, amphimixis) was "the only way" that hereditary influences "could arise

¹ Oscar Hertwig, *Der Kampf um Kernfragen der Entwicklungs- und Vererbungslehre*, Jena, 1909, pp. 44-45 and 107-108. See also *Nineteenth Century*, March, 1912, p. 520.

² To a review of this question in his capital work, *Heredity* (London, 1908, p. 64), Prof. J. Arthur Thomson added the following words: "Holding firmly to the view which we have elsewhere expressed, that life is a function of interrelations, we confess to hesitation in accepting without saving clauses any attempt to call this or that part of the germinal matter the exclusive vehicle of the hereditary qualities."

³ Rabi, *Ueber Organ-bildende Substanzen und ihre Bedeutung für die Vererbung*; E. Godlewski jun., in Roux's *Archiv*, vol. xxviii, 1908, pp. 278-378. The connection between all the cells in plants has been proved by observation, and now it begins to be proved for animals. The lively intercourse between the cells of the animal's body by means of the wandering cells, which was observed during regeneration processes, seems not to be limited to these processes. The researches of His, Kupffer, Loeb, Roux, and Herbst are tending to prove that the same cells also take part in the ontogenetic processes. (See the articles of Herbst in *Biologisches Centralblatt*, vols. xiv and xv.) *As to Nussbaum, whose work suggested to Weismann the "continuity" of the germ-plasm, his idea is that the germ cells are exposed to the same modifying agencies as the body cells (*Archiv für mikroskopische Anatomie*, xviii, 1908, quoted by Prof. Rignano in *La transmissibilité des caractères acquis*, p. 169.) Many other biologists come to the same conclusion.

⁴ Experiments of Ignaz Schiller on Cyclops and tadpoles; preliminary report in Roux's *Archiv*, xxxiv, pt. 3, pp. 469-470.

⁵ *Essays*, ii, 190.

and persist,"¹ Weismann soon had to abandon his amphimixis hypothesis (already repudiated long since by Darwin). Gradually he came to the hypotheses of "germinal selection," or struggle for food between the determinants of the germ plasm, as a probable cause of inherited modifications, and "parallel induction." In these two hypotheses he thus acknowledged that the germ cells are modified by external causes, so as to reproduce in the offspring the somatic, or body changes produced in the parent by the environment. Only in his second hypothesis he suggested that the germ cells are influenced directly by the external agencies—not through the modifications produced by the environment in the organs and tissues of the body. It hardly need be said that most biologists received this last suggestion not as a new working hypothesis but as a veiled concession of Weismann to his opponents. In fact, the hypothesis was not a generalization born from the study of changes going on in germ cells under the action of external agencies; it was advocated only as an hypothetical explanation for the facts that contradicted the previous hypotheses of Weismann. But till now, "we are told by the specialists who have studied the subject," it is impossible to ascertain in one single concrete case of inheritance how the modification was produced in the germ cells—through the body cells or independently of them.²

Some biologists saw in "parallel induction" an interesting new line of research, and they followed it. But Darwin, who already knew this hypothesis long before Weismann resorted to it, pointed out with full right, in *Variation*, that although a simultaneous modification in some definite direction of the body cells and the germ cells takes place in certain special cases, this can not be a general cause of the hereditary transmission of variations. Like Amphimixis, this hypothesis does not account for the inherited adaptive variations, the necessity of which for the evolution of new species Darwin already saw in 1868, and we still better see now.

In short, Weismann's attempt to combine the pre-Darwinian conception of innate predetermined variations with the Darwinian principle of natural selection has failed; and an attentive reader of his last work, *Vorträge zur Descendenztheorie*, especially the pages 258–315 of the second volume, will himself see how little there remained from that attempt. By his criticisms of some facts, which

¹ *Essays*, 1, 106.

² Cf. L. Plate, *Selektionsprinzip*, 4th edition, 1913, pp. 441–442. The same view, as it was pointed out by Prof. Hartog, is held by E. B. Wilson, the author of a standard work on the cell: "Whether the variations [he writes] first arise in the idiomplasm [the germ plasm] of the germ cells, or whether they may arise in the body cells, and then be reflected back upon the idiomplasm, is a question to which the study of the cell has thus far given no certain answer" (*The Cell in Development and Inheritance*, 2d edition, 1900, p. 433, quoted by Marcus Hartog in his work, *Problems of Life and Reproduction*, London, Murray, 1913, p. 198, chapter on the inheritance of acquired characters).

formerly used to be quoted as proofs of the inheritance of acquired characters, he certainly induced biologists to go deeper into the subject of heredity. But that was all. In his attempts at constructive work he failed. He had not that power of inductive generalization which leads modern science to its great discoveries. His hypotheses were brilliantly and imaginatively developed suggestions, but they were not brilliant inductive generalizations. They even lacked originality.

IV.

However, it may be asked: Why do we not know more cases where the hereditary transmission of acquired characters has been proved by experiment? Why have we not yet proofs of acquired characters being retained for a number of generations, even though the offspring was taken back to its old environment? These two questions certainly deserve a careful examination.

The reasons are many. To begin with, it is extremely difficult to breed plants, and still more so higher animals, in surroundings sufficiently different from the normal ones for altering the distinctive characters of a species. Especially is it difficult to make animals reproduce themselves in such conditions. In the best conducted experiments it happened over and over again that the second generation, when it was bred in an unusual environment, perished entirely; in the best cases only one or two individuals survived.

Besides, it was only gradually learned by the experimenters that, in order to obtain an inheritable variation, the modifying cause must act at a certain period of the individual's life, when its reproductive cells are specially sensitive to new impressions.¹ And then the experiments require time. While it is very difficult to breed several generations in succession in unusual conditions, it is precisely several, or even many generations which must be under the influence of a modifying cause in order to produce a more or less stable variation. Lamarck, in stating his two laws of variation, was careful to indicate that the changes must be slow, and that they must take place for a succession of generations, in order to be inherited and maintained later on for some time. Darwin repeatedly insisted upon this. But only now the conditions under which such experiments must be conducted are beginning to be realized in special climatic stations and laboratories. Up till quite lately such experiments were not in favor in most of the west European universities.

Finally, during the first decades after the appearance of the *Origin of Species*, research was chiefly directed, as we have seen,

¹ Darwin knew it and mentioned it in several places in *Variation*; but when the fact was established by the experiments of Merrifield, Standfuss, and so on, it was received as a new discovery.

to prove the very fact of a great variability of the species, even in their typical specific characters—this being denied then by a great number of zoologists and botanists. And later on a mass of experiments had to be made in order to prove that if plants and animals be placed in such conditions of temperature, moisture, light, and so on, as are offered in different regions of the earth, they will display exactly those variations which are characteristic of the floras and faunas of these regions, without any interference of natural or artificial selection. Besides, it was important to prove, and it was proved, that these variations, representing in most cases adaptations to the new conditions of life, could be produced by the new conditions themselves, which stimulate certain physiological functions (nutrition, evaporation, the elaboration of fats, and so on), and through them modify different organs.¹

Only after this immense work had been done—and it took more than 40 years—did biologists begin to investigate how far such variation is capable of giving origin to new races, and how many generations must be submitted to the modifying influences in order to produce a more or less stable variety.²

It must also be noted that at the outset inheritance experiments were chiefly made with variations in the colors and the markings of insects, and only now are they beginning to be directed toward the far more important study of variations in physiological functions, which are (as was indicated long since by G. Lewes and Dohrn, and lately by Plate) the chief agencies in the evolution of new races.

These are the causes which explain why the inheritance of environment-variations has not yet been proved by more experiments. However, it must not be forgotten that we know already two important groups of variations, both due to environment, which are inherited, and the inheritance of which is not contested. One of them is the inheritance of variations by means of bud-reproduction, and the other includes the so-called "sports," described by de Vries as "mutations."

¹ All this has been proved by experiment, and this is why a good-sized book would be required to record the results obtained lately by Experimental Morphology. Cf. T. H. Morgan's *Experimental Morphology*, New York, 1907; Przibram's *Experimental Zoologie*, Vienna, 1910; Yves Delage and M. Goldsmith, *Les théories de l'évolution*, Paris, 1909; and so on.

² That time was an important element in the problem was emphatically asserted by both Lamarck and Darwin, and even by Bacon. But there are Weismannians who overlook it. Thus Lamarck was reproached with having enunciated two contradictory statements in his first and second law. But such a reproach could only be made by overlooking the time that is required to produce the changes. To use Lamarck's own words, time is needed "both in gradually fortifying, developing, and increasing an organ which is active, and in undoing that effect by imperceptibly weakening and deteriorating it, and diminishing its faculties, if the organ performs no work" (first law). All that the second law says is, that what has been acquired or lost in this way is transmitted to the new individuals born from the former; but it says not a word about the length of time that the new character is going to be maintained, if the new-born individuals are placed again in new conditions or returned to the old ones. These individuals evidently fall in such case under the action of the slow changes mentioned in the first law.

With regard to the former I have already mentioned in a previous article¹ that Darwin, who had studied the subject, had shown that there is no means of finding any substantial distinction between reproduction by buds, cuttings, rootstocks, and the like, and reproduction by seed. The laws of both are the same, and in both cases the reproduction takes place by means of germ cells, capable of reproducing the whole plant with its sexual organs and with sexual reproduction, whether the germ plasm be contained in a seed or a bud, in the leaf of a begonia, or in the cambial tissue of a willow. And I have also shown that if Weismann, writing in 1888 under the fascination of his amphimixis hypothesis, made the grave mistake of thinking that there is no transmission of germ plasm in vegetative reproduction, and therefore described "bud-variation" as an "individual variation," he at least saw his error later on. He recognized in 1904,² using almost the same words as Darwin used in *Variation*, that a plant obtained through budding is as much a new individual as if it had been reproduced by seed.³

But it must be remembered that in the vegetable world reproduction by buds (rootstocks, runners, and the like) is far more important than reproduction by seed. In fact, it seems most probable that the immense majority of the plants which cover the northern part of the northern hemisphere have reproduced themselves since the glacial period chiefly by buds, runners, rootstocks and the like, as the Arctic and many Alpine plants still reproduce themselves. And as they transmitted to their offspring, during this long period of a chiefly vegetative reproduction, the characters they acquired in new surroundings, as they followed the retreat of the ice sheet, we can already say that an enormous number of sub-Arctic and Temperate Zone varieties and species owe their origin to the inherited effect of the direct action of changing surroundings.

It is very nice to say in poetical language that the steppes of south Russia are covered now with the same individuals of grasses that were withering under the hoofs of the horses during the migration of the Ugrians from the southern Urals to Hungary; but a botanist who knows that a bud on the rootstock of a grass contains the very same germplasm as the seed in its ear does not take these pretty images for a scientific induction.

¹ *Nineteenth Century and After*, October, 1914; pp. 821-825.

² *Vorträge*, 2d edition, vol. II, pp. 1 and 29.

³ Weismann is thus no longer responsible for those who go on repeating his opinions of 1888, when he believed that in vegetative reproduction we have only a subdivision of the same individual, and added "But no one will doubt that one and the same individual can be gradually changed during the course of its life by the direct action of external influences." (*Essays*, I, 420.)

V.

Much the same must be said about the so-called "sports," or inherited variations which seem to appear all of a sudden and have often given to breeders and growers the possibility of raising new varieties, or subspecies. Darwin paid them a good deal of attention; and in 1900, when the well-known Dutch botanist de Vries described the "sports" under the name of "mutations," and saw in them the real cue to the origin of species, interest in these "sudden" or "discontinuous" variations was renewed.

Already in Darwin's times it had been suggested that the "sports" may represent an important factor in the evolution of new species, and Darwin had shown the reason why this could not be the case (it will be mentioned further on). However, developed as it was by de Vries in a well-written work, rich in original observations, "the mutations theory" obtained for some time some success. The main objection against considering natural selection as nature's means of evolving new species being the insignificance of the first incipient changes in "continuous" variation, and their little value in the struggle for life, some biologists saw in the sudden variations, or "mutations," the means of getting rid of this objection, without resorting to the hateful direct action of environment.

De Vries based his theory chiefly on the sports of a well-known decorative plant, the evening primrose, or *Oenothera lamarckiana*, which he found growing wild in a field at Hilversum, near Amsterdam. It displayed there a number of "sports," and by cultivating these sports de Vries obtained a number of new "species."¹ These observations led him to build up a new theory of descent. According to it, the variations which Darwin described as "continuous," or "fluctuating," have no value for the appearance of a new species—not only because they are too small for having a life value in the struggle for existence, but also because they are not inherited, and consequently can not be "cumulative." The sudden "discontinuous" variations (Darwin's "sports") are known, on the contrary, to be inherited, and they often offer sufficient differences from the normal type to be of value for natural selection. In artificial selection they have been the means of obtaining new steady varieties.

In his earlier researches de Vries, who had studied for 15 years such inherited "monstrosities" as the five-leaved clover, and the many-headed poppy, had come, in accordance with Prof. J. MacLeod, to the conclusion that rich nutrition in the wide sense of the word

¹ Darwin probably would have described them only as "incipient species." Prof. Plate considers them as habitus modifications. They differ, he says, from the mother plant in many organs, but in each of them in an insignificant degree.

(heavy manuring, keeping the seedlings wide apart, and so on) was the first condition for obtaining such inheritable variations.¹ But later on, accepting the teachings of Weismann, he separated the "nutrition variations," which, he maintained, were not inheritable, from the "mutations." The latter were inherited, because they were originated by "congenital" variations, suddenly appearing for some causes unknown in the germ plasm, at certain periods of the life of the species. Each species, he said, has such a period, during which it can give origin to new species.

However, it was soon recognized by most botanists that the value of the *Oenothera* sports for a theory of descent had been overestimated. From accurate researches made in the United States, at Harlem, and in the environs of Liverpool, it appeared that the species described as *Oenothera lamarckiana* had a long history: it was cultivated in Europe as early as the middle of the eighteenth century, and it easily could be a crossing of two other species of the evening primrose. Hence its great variability.² Moreover—and this is an essential point, already noticed by Darwin—a variation is often described as a "sudden" one simply because the minute changes which were leading to its appearance were not taken notice of. In reality, leaving aside those unimportant individual differences which but feebly affect some organs, Darwin found no substantial difference between the sports and the inheritable fluctuating variations due to environment.³ As to the idea that sports might explain the appearance of new species, Darwin very wisely pointed out that purely accidental sports could not have played such a part in the evolution of new species, because they would not offer that accommodation to environment which can only be supplied by a definite and cumulative variation under the influence of a new environment—this variation being aided by natural selection.

At any rate, those who have seriously studied the whole subject of evolution and heredity, like Yves Delage, Johannsen, Plate, and many others, do not now attribute to "mutations" the importance that was going to be attributed to them a few years

¹ Cf. *Die Mutationstheorie*, vol. 1, Leipzig, 1901, pp. 93, 97-100, and in fact all the fourth chapter. Also his earlier articles, *L'unité dans la variation and Alimentation et sélection*, summed up in *Mutationstheorie*.

² Many important data concerning variation in *Oenotheras* will be found in the monograph of Messrs. D. T. MacDougal, A. M. Vail, and G. H. Shull, *Mutation, Variation and Relationships of Oenotheras*, Washington (Carnegie publications), 1907.

³ "Monstrosities graduate so insensibly into mere variations that it is impossible to separate them" (*Variation*, II, 297-298). He considered that "variability of every kind is directly or indirectly caused by changed conditions of life" (p. 300); and "of all causes which induce variability, excess of food, whether or not changed in nature, is probably the most powerful" (p. 302).

ago.¹ Prof. Ed. Bordage, who has published lately a special study of the whole question of mutations, also came to a similar conclusion.²

To begin with, Bordage points out that the *Oenothera lamarckiana* is, according to different botanical authorities, a hybrid, either between *Oe. grandiflora* and *Oe. biennis*, both imported to Europe in the eighteenth century (the former was known at Harlem since 1756), or between different varieties of *Oe. biennis*, which is a very variable species.³ But even if it was not a hybrid, the evening primrose has undergone so many changes in the conditions of its culture during the last 150 years that its present considerable variability may be a consequence of these changes.

All taken, Prof. Bordage comes to the opinion that a mutation is not something substantially different from an ordinary variation. It is only "a sudden external expression of internal processes, accomplished gradually and without interruption. * * * Between the sudden and the slow variation there is no absolute difference. Both can be considered as the effects of the same law, manifesting themselves more or less rapidly."

VI.

"Mutations," we have just seen, were described as "congenital variations." But every variation of form and structure, once it is inherited, implies a "congenital variation." Some change must have taken place in the germ cells whatsoever the origin of the variation or the position of the germ cells in the organism may be. We learn, it is true, from the experiments of MacDougal and Tower that certain inheritable changes may be obtained by a direct action of external agencies (temperature and so on) upon the germ cells. Of course, they may. But nobody has yet proved that changes produced in the body cells can not affect the germ cells, while modern research tends to prove quite the contrary.

Consequently, we are not astonished to learn that de Vries, having recognized in his last work, *Gruppenweise Artbildung*, that every

¹ Thus, fully recognizing that "de Vries has established in the domain of heredity a mass of facts, the theoretical value of which still remains in some respects to be established by further research," Prof. Plate, in analyzing the mutation theory in his monumental critical work (*Selektionsprinzip*, pp. 384-435), wrote: "The mutation theory obtained an apparent temporary success because it introduced new words for well-known facts and conceptions, and thus awakened the idea that a new knowledge had been won. It is evident that for the theory of descent no real progress in advance of Darwin had been won in that direction." In another very elaborate work, *Vererbungslehre* (vol. II, of his *Handbücher der Abstammungslehre*, Leipzig, 1913, pp. 430-475), Plate returned once more to this subject, and after a careful examination of the whole question (including Mendelism) he worded his final conclusion as follows: "Those thoughts in it [the mutations theory] which are correct are not new, and its new components can not be accepted" (p. 478).

² "Les nouveaux problèmes de l'hérédité: la théorie de la mutation," in *Biologica*, II, 1912.

³ The latter is the opinion of Mr. Boulenger, an authority on the subject; and the former is the view taken by Davy and several other botanists.

mutation must have "not only an inner cause, but also an exterior cause," and that the high variability of the *Oenotheras* must be "to some extent a consequence of the special conditions of the soil,"¹ has thus given a hard blow to the idea of a fundamental distinction between "mutations" and ordinary variation. Both are inherited, the difference being only one of degree in the modifying cause.

It may be added that Erwin Baur, who also has carefully studied the subject, comes to a similar conclusion in his *Introduction to the Experimental Theory of Heredity*. As a rule (he writes) mutations are rare (one in a thousand individuals, or less); and "what are their causes in most cases we don't know." Only lately experiments were made showing that mutations (i. e., inheritable variations) can be provoked by exterior influences, depending on our will. Such are the experiments on the Colorado beetle made by Tower, who used high temperatures, dryness of the air, and low atmospheric pressure, those of Blaringhem, who provoked inherited variations by mutilations of plants, and MacDougal, who acted directly on the reproductive cells.²

Finally we learn from another most careful and gifted experimenter, Professor Klebs, that those characters of a plant which belong to the most constant ones under the ordinary conditions of culture can become most variable under properly chosen conditions; and that both the so-called continuous and the discontinuous variations (the mutations) can be obtained in the same individual, according to the external conditions into which it is placed.³

The consensus of opinion is thus against attributing to mutations an origin quite different from the origin of habitus variations. But once it is so, we have in the so-called "mutations" another vast category of characters "acquired" under the influence of a changed nutrition in a new environment, and inherited.⁴ And these two vast cate-

¹ De Vries, *Gruppenweise Artbildung*, pp. 342-343; also *Species and Varieties: their Origin by Mutations*, Lectures before the University of California, edited by D. T. MacDougal, Chicago, 1906, p. 451.

² Erwin Baur, *Einführung in die experimentelle Vererbungslehre*, Berlin, 1911, pp. 202-204. In a recently published work by R. Ruggles Gates, *The Mutation Factor in Evolution*, with particular reference to *Oenothera* (London, 1915), we have an important contribution to this subject. Its chief interest is in the researches made by the author to discover the changes which take place in the germ cells when an inherited variation takes place in the extremely variable complexus of species and varieties represented by the *Oenothera*. These researches have not yet brought the author to a definite conclusion as to the causes of mutations (p. 321); but they open an interesting branch of investigations in the great question of heredity.

³ "Studien über Variation," in Roux's *Archiv*, vol. xxiv, pp. 29-113; review in *Année biologique*, xiv, p. 357.

⁴ With all the respect I have for the always most accurate work of Prof. J. Arthur Thomson, I confess that, whatever his other reasons in favor of discontinuous variation may be, the facts he mentions in *Heredity* (London, 1908, pp. 86-89) hardly prove that "variation leads by leaps and bounds." The very words with which Prof. Thomson accompanies, with his habitual fairness, each of the examples he mentions, suggest that there is no reason to affirm and some reason to doubt that the new characters appeared suddenly. About the wonder horse with an extremely long mane we are told that "the parents and grandparents had unusually long hair"; about the Shirley poppy, that the "single discontinuous variation" from which it was obtained "may have occurred often before Mr. Wilks saved it from elimination"; but no reason is given to suggest that it was a "sudden" variation; the same applies to the star primrose, the moth *Amphidasys*, and the medusoid *Pseudoclitia pentata*, which is said to be "remarkably variable."

gories immensely reduce the part that natural selection may have to play in the evolution of new species. With this reduced function it becomes quite comprehensible.

VII.

The dominating tendency of modern research is thus to come to a synthesis of the two chief factors of evolution—the Buffon-Lamarckian factor, including the variations called forth by a changing environment, and the Darwin-Wallacian factor of natural selection. Darwin, as we saw, frankly acknowledged it.

Herbert Spencer had already come to this conclusion, only giving even more importance to the first factor:

The foregoing chapters, he wrote, in the second enlarged edition of his principles of Biology, imply that neither extreme (i. e., natural selection alone, or the direct action of environment without the aid of natural selection) is here adopted. Agreeing with Mr. Darwin that both factors have been operative, I hold that the inheritance of functionally caused alterations has played a larger part than he admitted even at the close of his life; and that, coming more to the front as evolution has advanced, it has played the chief part in producing the highest types.

It is most interesting to note that Weismann, although his starting point was quite different from that of Darwin and Spencer, also came, after all, to the same views. He began by proclaiming the “all-sufficiency of natural selection” for giving origin to new species, and rejected the necessity of inheritable adaptive changes being produced by the environment. But we saw how he gradually came to new hypotheses, which actually recognized the part played in the evolution of new species by inherited variation.

Pages could be covered to show how biologists engaged in experimental work came, after some hesitation, to recognize the modifying influence of environment. But a few quotations will do to show the general tendency of modern research.

Standfuss has summed up the results of his 24 years’ experiments in a carefully worded lecture. He sees in the predominance of an older type upon a newly appearing variation the key to the difficulty of a transmission of acquired characters to the offspring. The grip of the old stirp—of what has become strongly established during a succession of generations—can not, Standfuss says, be easily overpowered by the new (a view, by the way, expressed already by Bacon). And after having proved by his experiments that sometimes the new is inherited, Standfuss concludes his lecture with these words:

The mutual interaction between the agencies of the outer world and the organisms gives origin to fluctuating (*schwankenden*) new forms; they are

inherited more or less, then they are sifted by selection, and kept by it within definite lines of development.¹

Wettstein, who has been experimenting for years upon the modification of plants by exterior agencies, openly accepts the hereditary transmission of acquired characters in his *Handbook of Systematical Botany*. He writes:

In the immense majority of cases adaptive characters are originated by the so-called "direct adaptation"; in other words, we must recognize in the plant the faculty of adapting itself directly to the prevailing conditions of life and inheriting these acquired adaptation characters.²

J. P. Lotsy, the author of a well-known elaborate work on the theories of descent, comes to the conclusion that—

unless we accept a *vis vitalis* (a life force) which, after all, would explain nothing, it is impossible to find another reason for the origin of variations but the influence of the external conditions on the substance of the protoplasm, and without an inheritance of the acquired variation, or character, there is no reason for its being fixed. If one absolutely denies the possibility of biometamorphoses (variations due to environment) being inherited, this means to deny evolution itself.³

D. T. MacDougal, after having analyzed the work of Buchanan, Gages, Klebs, Zederbaum, and de Vries, finds that their discoveries, coupled with his own and other botanists' work at the Desert Botanical Laboratory in the United States and elsewhere, enforce upon us the conclusion that structural changes and implied functional accommodations are without doubt direct somatic responses, which became fixed and permanent in consequence of their annual repetition through the centuries.⁴ W. Johannsen, whose main work, *Elements of the Exact Science of Heredity*,⁵ is held in high esteem by biologists of all schools, comes, in one of his latest writings, to the conclusion that without inherited variations "selection would have no hereditary influence."⁶ And so on.

VIII.

The idea of natural selection apparently did not occur to Lamarck, although several passages in his works suggest that he had noticed the struggle for existence. As to the modern Lamarckians, while nearly all of them indicate the limitations of natural selection, they

¹ M. Standfuss, "Zur Frage der Gestaltung und Vererbung," lecture before the Zurich Naturalists' Society, in January, 1902. Zurich, 1905 (separate reprint).

² *Handbuch der systematischen Botanik*, Vienna, 1901 seq. I quote from Adolph Wagner's *Geschichte des Lamarckismus*, Stuttgart, 1909, p. 215.

³ *Vorlesungen über Descendenztheorien*, vol. II, Jena, 1908.

⁴ "The Inheritance of Habitat Effects in Plants," in *Plant World*, xiv, 1911; analyzed in *Botanisches Centralblatt*, Bd. cxxii, 1913, p. 134.

⁵ *Elemente der Exakten Erblchkeitslehre*, Jena, 1909, pp. 308, 449, etc.

⁶ "The Genotype Conception of Heredity" in *American Naturalist*, xlv, 1911, quoted by Semon in *Verhandlungen des Naturforschers-Verein in Brunn*, vol. lxi.

do not exclude its action from their schemes of evolution. 'They only object to the exaggerated part attributed to it by those whose conceptions of descent are influenced by their sociological or supernatural consideration, and they understand that natural selection surely gives stability to the effects of the direct action of environment. Most of them also recognize that by the side of these two main factors of evolution one must take into consideration the two aspects—individual and social—of the struggle for life, the development of protective instincts in the higher animals, and the effects of use and disuse of organs, crossing, and the occasional appearance of more or less sudden variations—all these having their part in the evolution of the unfathomable variety of organic forms.

Among the modern biologists, Prof. Plate has perhaps best understood the necessity of a synthetic view of the factors of evolution, which he has developed in his elaborate work, now known under the title of "Selektionsprinzip." He examined first in detail the scope and the possibilities of natural selection under the different forms of the struggle for life, and after having shown that natural selection steps in where the Lamarckian direct adaptation fails, and that single-handed it would not be sufficient to solve the problem of the origin of species, Prof. Plate sums up his opinions in the following lines which, in the present writer's opinion, are a fair statement of the case:

The only real difficulty for Darwinism is [he writes] that the variations must attain a certain amplitude before they are "selection-worthy"; that is, before they give to selection the opportunity to step in. Minimal individual differences can call forth no selection. However, I have shown already at some length (pp. 109-179) that after a careful study of the problem this difficulty proves to be illusory, because, on the one hand, it is impossible to deny that there are variations worthy of being selected,¹ and, on the other hand, there are in nature different ways for increasing the minimal differences, so that they do become worthy of selection. Of these different ways, the modification of functions, the changes in the conditions of life, use and disuse, and orthogenesis enter into the category of the factors indicated by Lamarck, and therefore the selection theory can not refuse the collaboration of the Lamarckian factors. Darwinism and Lamarckism,² taken together, give a satisfactory explanation of the growing up of species, including the origin of adaptations, while neither of these two theories, taken separately, gives it. (Selektionsprinzip, pp. 602-603.)

Let me only add, to avoid misunderstandings, that the Lamarckism of which I have spoken in these pages and which Plate has in view in the just given quotation means the teachings of Lamarck as they appeared in his *Philosophie zoologique*, his remarkable *Discours d'ouverture de l'an X et de l'an XI*, delivered at the Academy of

¹ One must, however, ask whether such sudden variations appear in sufficient numbers.—P. K.

² "I mean, of course [he added in a footnote], only the causal-mechanical part of Lamarckism, not its autogenetical and psychical ideas." See pp. 501, 504.

Sciences at Paris, and his *Système analytique des connaissances positives de l'homme*, of which the last two are entirely ignored in this country and the first is frequently misquoted. These teachings show that Lamarck had not the least leaning towards a metaphysical *Natur Philosophie* and they have nothing to do with the vitalist and other theories of the German Neo-Lamarckians, of whom Francé (a distinguished botanist) and Dr. Adolph Wagner are prominent representatives.¹

A synthesis of the views of Darwin and Lamarck, or rather of natural selection and the direct action of environment, described by Spencer as direct and indirect adaptation, was thus the necessary outcome of the researches in biology which have been carried on for the last 30 or 40 years. If considerations lying outside the true domain of biology, such as those which inspire the neo-Lamarckians and inspired Weismann, cease to interfere, a synthetic view of evolution (in which natural selection will be understood as a struggle for life carried on under both its individual and its still more important social aspect) will probably rally most biologists. And if this really takes place, then it will be easy to free ourselves from the reproach which has been addressed to nineteenth-century science—the reproach that while it has aided men to liberate themselves from superstitions, it has ignored those aspects of nature which ought to have been, in a naturalistic conception of the universe, the very foundations of human ethics, and of which Bacon and Darwin have already had a glimpse.²

Unfortunately the vulgarisers of the teachings of Darwin, speaking in the name of science, have succeeded in eliminating this deeply philosophical idea from the naturalistic conception of the universe worked out in the nineteenth century. They have succeeded in persuading men that the last word of science was a pitiless individual struggle for life. But the prominence which is now beginning to be given to the direct action of environment in the evolution of species, by eliminating the Malthusian idea about the necessity of a competition to the knife between all the individuals of a species for evolving new species, opens the way for a quite different comprehension of the struggle for life, and of nature altogether.

¹ See R. H. Francé, *Der heutige Stand der Darwin'schen Fragen*, Leipzig, 1907; and Dr. Adolf Wagner, *Geschichte des Lamarckismus*, Stuttgart, 1909.

² Cf. "The Morality of Nature," in *Nineteenth Century*, March, 1905.

ON THE LAW OF IRREVERSIBLE EVOLUTION.¹

BY BRANISLAV PETRONIEVICS, PH. D.

Louis Dollo, the great Belgian paleontologist, first publicly formulated in 1893 (Dollo, 4) his famous law of irreversible evolution, one of the most important laws of the evolution of organized beings.² This law has often been debated and applied, but I do not know that anyone has attempted to set it forth, basing his exposition on Dollo's own works. This is what I propose to do here, adding to my account some critical remarks on the value of the law in question.

The law of irreversible evolution was stated by Dollo as follows:

An organism can not return even in part to a previous condition already passed through [*déjà réalisé*] in the series of its ancestors. (Dollo, 4 p. 165.)³

It is usually supposed that the law thus expressed applies only to parts and organs which are reduced or eliminated; but this is not correct. The law is much wider in its application, covering functional organs as well. In order to understand more clearly the far-reaching nature of Dollo's law we must make certain distinctions in the concept of organic evolution and give some definitions of them.

Organic evolution may be, as we know, progressive, regressive, and mixed.⁴ If, during mixed evolution (which is the most wide-

¹ Translated, with permission, by Gerrit S. Miller, Jr., from *Science Progress*, January, 1919.

² He previously stated this law in 1892, in his *Cours autographié*, etc. (Dollo, 1), the same year in a note which appeared in the *Bulletin de la soc. belge de Géol.*, etc. (Dollo, 2) and in an article which appeared in *A. Gildard's Bulletin scientifique de la France et de la Belgique* (Dollo, 3).

³ Later, Dollo expressed his law with greater exactitude:

"An organism never exactly renews a previous condition, even if it finds itself placed in an environment identical with one through which it has passed. But, by virtue of the indestructibility of the past, it always retains some trace of the intermediate stages which it has traversed." Dollo 17, p. 107, and 10, p. 443.) Let us note that Dollo definitely admits the reversibility of conditions of existence: "Evolution is irreversible as regards the structure of organisms * * *, but reversible as regards environment (Ethology)." (Dollo, 7, p. 15.)

⁴ In my course of independent lectures (on universal evolution) given at the Sorbonne this year, which will later be published, I have defined evolution in general as follows: "Evolution is a thing's coming into being by successive stages of change." When each successive stage of the evolutionary process contains something more than the preceding stage, evolution is progressive; it is regressive when each successive stage contains something less than the preceding. Evolution is mixed when in an evolving whole one part evolves progressively and the other regressively.

spread type in the domain of organic evolution) progression predominates, or, to put it in another way, if the final condition reached represents progress in comparison with the initial condition, we then shall call such a mixed evolution "ascending evolution," and of this process the extreme type is represented by pure progressive evolution with or without the addition of new parts. But if, in mixed evolution, regression predominates, or, in other words, if the final condition reached is a regress in comparison with the initial condition, we shall call mixed evolution of this kind "descending evolution," pure regressive evolution evidently representing the extreme type of such a process. The foot of the horse, made of a single digit, which has come from a pentadactyle foot by the atrophy of the lateral digits and the great increase of the median digit, is the best-known example of ascending mixed evolution, while the skull of the living *Ceratodus*, in comparison with that of *Dipterus*, its probable Devonian ancestor, presents an example of descending mixed evolution.

Taking into consideration on the one hand, the definitions which we have just made, and, on the other, the examples cited beyond, which Dollo brought forward in favor of his law, we ought to separate the cases of ascending evolution from those of descending evolution, something which Dollo himself did not do. Clearly, if the structure of an organ or if the parts of an organ are lost through *descending* evolution, and if it is not possible, as is almost unanimously agreed, to replace the lost structure or parts, it does not at all follow—at least *a priori*—that a reversal of evolution would not be possible in the contrary case; that is, when the structure of an organ has been lost by the *ascending* evolution of this organ.

We should therefore replace Dollo's single law by three different laws, one of which, the first and most fundamental, will express the impossibility of a reacquisition of lost parts, the second of which will apply to the cases in which the original structure of an organ has been lost by ascending evolution, and the third to the cases in which the structure has been lost by descending evolution.

These three laws are as follows:

1. Organs and parts of organs reduced or lost through regressive evolution can not be regained by a new progressive evolution.¹

2. If the original structure of an organ has been lost through ascending evolution (with or without the addition of new parts) the original structure can not be regained:

- (a) By the reacquisition of the lost parts, this reacquisition being impossible according to the first law.

¹ For the first law, see Dollo, 7, p. 5 (the lost interclavicle of *Dermochelys*), Dollo, 9, p. 130 (the atrophied pineal eye of *Platycarpus*), and Dollo, 16, remark 2, p. 400.

(b) By the regressive evolution of the new parts, the total disappearance of these parts being impossible.

(c) By the ascending evolution of these new parts in a new direction.

3. If the original structure of an organ has been lost through descending evolution (with or without the loss of parts), this original structure can not be regained:

(i) By the reacquisition and progressive evolution of the lost parts, this reacquisition being impossible according to the first law.

(ii) By the ascending evolution of the nonreduced parts in a new direction.

(iii) By the ascending evolution of altogether new parts.

II.

The various cases falling under these three laws we wish now to explain by examples found in the writings of Dollo.

For the first law examples are very numerous. The birds lost their teeth during the Cretaceous period; no subsequent bird has been able to regain these lost parts. The mandible of mammals consists of a single piece homologous with the dentary part of its reptilian ancestors; no mammal has been able to regain the lost other parts of the reptilian jaw, etc.

But the examples that especially demonstrate the validity of the first law are those in which the return to ancestral conditions would necessitate the reappearance of parts which an organism has lost. As these examples are at the same time illustrations of the two other laws we shall deal with them in connection with these laws.

The best-known example of the first alternative under the second law is the pseudo dentition of *Odontopteryx*, an Eocene fossil bird. Instead of the true teeth that have been lost, *Odontopteryx* has the margin of the beak and of the lower mandible dentate like a saw.

The most striking example of the second alternative under the second law is the pelvis of *Triceratops*. The dinosaurian ancestors of *Triceratops* had become adapted to bipedal life, and therefore were possessed of a very long and very narrow ischium and of a pubis provided with a postpubis which was similarly very long and very narrow (Dollo, 10, p. 444). In its secondary adaptation to quadrupedal life *Triceratops* was not able morphologically to regain the triardiate pelvis of its far-distant quadrupedal ancestors, for it has retained traces of the bipedal phase in the rudimentary postpubis and in the narrow, recurved ischium. That is to say, the postpubis, the new structure acquired during bipedal life, could not totally disappear, and the new form of the ischium could not disappear either (Dollo, 10, p. 446).

The most important and most obvious example of the third alternative under the second law is also found in a dinosaur, nearly related

to the preceding, *Stegosaurus*. This animal had for its immediate ancestors bipeds like the ancestors of *Triceratops*, and, like *Triceratops*, it became readapted to quadrupedal life. But while the triradiate pelvis of its far-away quadrupedal ancestors has been physiologically reestablished through regressive evolution (atrophy) of the postpubis and ischium in *Triceratops* (Dollo, l. c. p. 446) these parts have evolved in a new direction in *Stegosaurus*. Here the ischium becomes shortened and flattened; the postpubis does the same and moreover applies itself closely along the ventral margin of the ischium. But morphologically there is here no return to the former triradiate condition of the pelvis, since the ischium has kept some trace of the form which it acquired in the biped phase, and the posterior branch of the pelvis is no longer formed by the ischium alone but by the ischio-postpubic complex. While evolving in the new direction the postpubis has thus changed in function (Dollo, l. c. p. 447).

We find an illustration of the first alternative of the third law in the evolution of the arms in the Octopods. These animals in adapting themselves to bottom sea life have lost a pair of arms (the tentacular arms) possessed by their immediate ancestors the heteropod decapods. They have thus become isopods again (excepting the peculiar case of the Argonaute, and the hectocotylisation of one of its arms) like their distant ancestors the Belemnoteuthids (isopod decapods) without having been able to regain the same number of arms (see Dollo, 17, pp. 115-116).¹

The best illustration for the second alternative of the third law is the foot of *Dendrolagus*, an arboreal Kangaroo. The structure of the foot in the saltatorial Macropodidae—the predominance of the fourth toe, the syndactylism of the second and third, the reduction of the fifth and the complete disappearance of the great toe—shows us that their immediate ancestors were arboreal. In *Dendrolagus*, a Macropodid which has again become arboreal, the opposable great toe, completely atrophied in its immediate ancestors the terrestrial kangaroos, was not able to reappear. But the unreduced parts of the foot have undergone an ascending evolution in a new direction. While the metatarsals and the phalanges have diminished in length, the phalanges and claws have become lengthened and the claws have at the same time become curved. Thus the foot of *Dendrolagus* has not been able to return to the structure of the foot of its distant

¹ A still more convincing instance would be the secondary steganocephaly of the chelonians. This steganocephaly differs from the primary steganocephaly of the ancestral steganocephalous amphibians in that the postorbital, the supratemporal, and the epiotic do not reappear in the cranial vault when once lost (see Dollo, 19, p. 59). But the secondary steganocephaly of the chelonians, although very probable (see especially the recent note by G. A. Boulenger, "Sur la place des Chéloniens dans la classification" in *Comptes rendus*, vol. 167, 1918, p. 514), is not yet beyond doubt. See D. M. S. Watson, *Eumotosaurus africanus*, in *Proc. Zool. Soc., London*, 1917, p. 1011.

ancestors, which possessed an opposable great toe, syndactyly of the second and third toes, dominant fourth toe, and reduced claws. (See Dollo, 6, pp. 194 and 199.)

Finally, for the third alternative of the third law we have an illustration in the secondary carapace and plastron of the turtle *Dermochelys*. The distant ancestors of this turtle were, like it, sea-turtles; its reduced primary plastron (a ring formed of four pieces) and its still more reduced primary carapace (represented by the nuchal plate alone) bear witness to the fact. When adapting themselves to littoral life the immediate ancestors of *Dermochelys* reacquired a carapace and a plastron, but this carapace and plastron are entirely new structures of superficial dermal origin. Readapting itself to marine life *Dermochelys* has preserved this carapace and plastron of its immediate ancestors, although both are already much reduced. (See Dollo, 7, pp. 9-14.)

III.

The importance of the law of irreversible evolution is multiple. In the first place, this law has a phylogenetic application, that is, it places us in position to reconstruct, with the often insufficient paleontological material which we possess, phylogenetic series which, if they are not true series are at least series which represent indubitable evolutionary stages. Its ethological application is yet more considerable. It is often the only means of determining the conditions of existence and the method of adaptation to life of fossil organisms. But sometimes this law has a morphological importance also, because by using it we can distinguish homologies from mere analogies. Finally Dollo has shown that it can act also as a guide in classification, that it therefore has a systematic application.

The most important phylogenetic application of the law was made by Dollo in the difficult question of the phylogeny of the Dipnoi. Dollo's very ingenious paper on this subject (Dollo, 5) should be considered a model presentation of the philosophic point of view in the new paleontology. Before Dollo this subject was in a truly chaotic state, one of the most eminent paleontologists having declared *Dipterus*, the oldest and most primitive type, to be the most specialized.¹ Nowhere else has the conception of the irreversibility of evolution given such brilliant results. Since this conception expresses the idea that we never fully return to an ancestral structure it can be used to determine whether a particular condition is primary or secondary. Consequently it can be used to decide upon the direction of evolution when we have a series containing a sufficient num-

¹ See A. S. Woodward, *Catalogue of the Fossil Fishes in the British Museum*, pt. 2, 1891, p. XX. But after Dollo published his important memoir Woodward accepted his conclusions. See his presidential address to the Section of Geology, in *Nature*, vol. 81, 1900, p. 292 (and Dollo, 16, rem. 2, p. 387).

ber of terms intermediate between the extremes (Dollo, 5, p. 97¹). Just such a series we possess in the paleontological series of the Dipnoi: *Dipterus valenciennesi*, *Dipterus macropterus*, *Scaumenacia*, *Phaneropleuron*, *Uronemus*, *Ctenodus*, *Ceratodus*, *Protopterus*, *Lepidosiren* (l. c., p. 88). Dollo shows that the structure of the tail as well as that of the top of the head, the squamation, the pugal plates, the opercular apparatus, the ganoin, and the ossification of the mandible, the suborbital band—all this proves that the course of evolution has been in the direction from *Dipterus* to *Ceratodus*. and not the opposite (l. c., p. 89-97). It is especially by the structure of the tail that the concept of irreversibility is illustrated. In a long and thorough treatment of the subject Dollo shows (l. c., pp. 89-97) that the diphyccercal tail of the Dipnoi (and of the other known ancient and modern fishes) is a secondary diphyccercal tail whose morphological value in the Dipnoi (the second dorsal fin, the second anal fin) is not equivalent to the morphological value of the primitive diphyccercal tail (caudal fin). In this secondary diphyccercal condition there is therefore no return to the primitive structure.

The most important other cases of phylogeny which Dollo has considered are the phylogeny of the sirenians (Dollo 3, p. 119), the phylogeny of the Leather-backed turtle (Dollo, 7, p. 9), and the phylogeny of the Holocephali (Dollo, 13, p. 107).

One of the most important cases with regard to the ethological application of the law of irreversibility is found in the memoir on the Dipnoi. If it be assumed that *Dipterus* comes from *Ceratodus*, as the latter is an adaptation to life in turbid water, it would be necessary to suppose either that *Dipterus* represents an adaptation to life in mud (excessively turbid water), or else that it represents a return to life in clear water. The first alternative being that of *Lepidosiren*, the second is the only one which remains open for discussion (Dollo, 5, p. 99). But, putting aside paleontological and purely ethological reasons, the law of irreversibility is sharply opposed to such a view.

"Would the lost ganoin return? Would the cephalic shield resolve itself into its ancestral elements? Would the suborbital band with its ossicles in varying number become once more a solid arch? Would the opercular apparatus resume its original dimensions? Would the vanished jugular plates reappear?" As all of these structures are reduced in *Ceratodus* (l. c., p. 100), *Dipterus* can only represent a primary adaptation to life in clear water, that is to say it is purely a fish ("the most pisciform of Dipnoi," l. c., p. 101).

¹ Discussing the subject of the phylogeny of the Holocephali (Dollo, 13, pp. 107-108), Dollo says: "The idea of the irreversibility of evolution, which has led me to the results that I have just demonstrated, has once more shown its usefulness. Without it one would be led to assert that specialized organisms could become primitive again and then once more specialize themselves in the same or another direction. Such an assumption, unless supported by absolutely complete paleontological series—which we are far from possessing—would destroy all possibility of discovering phylogeny, the main object of morphology."

Another important instance of the ethological application is furnished by the bipedal habits of the immediate ancestors of *Stegosaurus* and *Triceratops*.

If evolution were reversible these two dinosaurs would have exactly regained their former quadrupedal structure, and there would have been no way to distinguish their secondary quadrupedal existence from the first (Dollo, 10, p. 448).

The other most important cases of ethological application are: The secondary adaptation to the swimming sea life of the Pycnodonts (Dollo, 17, pp. 108-9), the secondary adaptation to the swimming sea life of the Trilobites *Dephon* and *Aeglina* (Dollo 16, pp. 410 and 412), etc.

Among the instances of the morphological application of the law, that of the secondary abdominal ventral fins in the teleosts has a special importance. As is known, the ventrals of teleosts may be either abdominal or thoracic or jugular. But among the abdominal ventrals we have two types—those which have no connection whatever with the pectoral girdle, and those joined to the clavicular symphysis by a ligament. As there is no reason for the presence of this ligament in situ we have to conclude that it is the degenerate remnant of a former direct connection with the pectoral girdle. In conformity with the irreversibility of evolution the ventrals in again becoming abdominal have kept the connection with the clavicular symphysis which they acquired when occupying a thoracic or jugular position (Dollo, 14, p. 139).

The other important instances of the morphological application of the law are: (1) The very anteriorly placed choanae of the sea turtles (Dollo, 8, pp. 817-820), (2) the longirostral and brevirostral condition in Crocodilians (Dollo, 12, p. 85), etc.

Finally, we must mention the one instance in which Dollo has used his law in systematic work—the Ptyctodonts. Before Dollo these fossil fishes, then known from their dental plates only, had been placed among the Holocephali. In his important memoir on this subject (Dollo, 13) Dollo showed that, by virtue of the law of irreversible evolution, the Ptyctodonts can not be regarded as Holocephali and that they ought to be treated as Arthroderes. Since then Dollo's conclusion has been wholly confirmed.

Although the empiric evidence for the validity of his law has been abundant and varied, Dollo was not satisfied with such a wholly empiric demonstration. He has attempted to give a deductive demonstration as well. He says:

The Irreversibility of Evolution is not, as many have believed it to be, merely an empiric law based purely on facts of observation. But it has deep-seated causes which carry it in final analysis to a question of probabilities, as in the case of the other laws of nature. Evolution being a summation of exactly determined individual variations in an exactly determined order, to have it reversible would be to admit the possibility of the intervention of causes exactly the inverse of those which produced and fixed the individual variations from which the first transformation arose, and in an exactly inverse

order—circumstances too complex for it to be imagined that they are ever realized. (Dollo, 19, p. 59, rem.; see also Dollo, 3, p. 127.)

And, when speaking of the impossibility of the descent of *Dipterus* from *Ceratodus* (Dollo, 5, p. 100, the passage referred to above) he says:

And let it be noted that it is here a question not of one isolated character, but of a whole group of characters, something that is much more serious so far as irreversibility is concerned * * * But it is particularly in its action on elements as multiple as these that we can affirm with certainty that evolution is not reversible (l. c. rem. 72, p. 122).

The irreversibility of evolution becomes, therefore, according to Dollo, the more probable as the number of elements increases, and it is practically a necessity when the number of elements is considerable.

IV.

Having explained the law of irreversible evolution, the various cases which it makes clear, also its applications, and its logical basis, we now wish to make some critical remarks on the various aspects of the law.

In the first place, its logical basis. The deductive demonstration of his law, attempted by Dollo, is very doubtful. As to the number of elements on which evolution acts, it is not a question of cells, but of organs and parts of organs (because it is only these last which have their peculiarities determined in the germ), and the number of these organs and parts is not relatively great even in the most complex organism. But, if we consider the much greater number of individuals in which the organs and parts of organs show individual variations, the chance that they will vary in different directions and consequently also in inverse directions becomes possible. It is only if we assert that individual variations are relatively not very numerous—predetermined—that this course of reasoning founded on pure probability becomes weak. In that case, however, the law of irreversible evolution is not the result of numerical probability, but the result of unknown internal causes of organic evolution.

There is, therefore, no logical necessity in the law of irreversible evolution, and this law remains a purely empirical rule. Let us now see how much the three laws of this evolution are confirmed by experience, and to what extent we should expect possible exceptions.

As to the first law,¹ this law appears to be without exceptions so far as it applies to lost organs and parts. For the loss of an organ or of a part having become final by the loss of the corresponding tendency in the germ, it is almost impossible to imagine the reappearance of this tendency, bearing in mind, on the one hand, the

¹ Compare the similar observations of A. Handlirsch, 24, p. 1328 (cited by Dollo, 15 rem. (2), p. 429).

difficulty of producing new tendencies in the germ by the influence of external causes, and on the other the degree of correlation that would be needed among these tendencies. When it is a question of the reduction of an organ or part, two alternatives must be distinguished. If the reduction has gone so far that the corresponding tendency in the germ is verging on complete disappearance, the reduced organ or part will find itself practically in the same condition as if it were already lost. But if their reduction has not reached to such an extreme their evolution in an inverse direction will not be impossible.

For the second law we must distinguish between the case of a single part and that of a complex organ. The regressive evolution of a single part, if during this evolution and the preceding progressive evolution no change of form has taken place, could clearly lead back to the point where the progressive evolution started. And the regressive evolution of a single part, if the corresponding arrangement in the germ is not too much enfeebled, could evidently also be followed by a new progressive evolution. But if a change of form has taken place during the first progressive evolution, and if this change of form has been so great that a change in the corresponding arrangement of the germ has been necessary, then neither the regressive evolution following the original progressive evolution will be able to lead back to the point of departure of the latter, nor will a new progressive evolution have the power to accomplish it, because to do so would necessitate the return to a disappeared condition. If, for instance, a tooth has first increased in size and afterwards diminished without change of form this tooth will be able by diminution to assume the dimensions which it had at the beginning of its increase, and a new increase of the same kind will not be impossible (if the reduction has not gone too far). But if the increase in size has been accompanied by a radical change of form, if, for instance, a conical tooth has become laterally compressed, then a return to the conical form will not be possible either during its diminution¹ or during a new increase in size.

In the case of a complex organ Dollo asserts that its return to the previous condition through the action of regressive evolution is impossible on account of the "indestructibility of the past." But if a single reduced part of an organ is regarded as the supposed reason why reversibility is impossible, we are able to affirm almost with certainty that in such a case the indestructibility of the past does not exist, because it would find itself in contradiction with the well es-

¹ This impossibility is exactly what W. D. Matthew supposes to have happened during the evolution of the *Felidae* when he supposes that the felines come from *Dinictis*, a primitive saber-toothed cat (see W. D. Matthew, "The Phylogeny of the *Felidae*," Bull. Amer. Mus. Nat. Hist., vol. 28, 1910, p. 290 s). Scott has clearly had a glimpse of the fact that this phylogeny contradicts the law of irreversible evolution (see W. B. Scott, 28, p. 540 s).

tablished law of the necessary regressive evolution of nonfunctional parts and organs. The reversibility of the ascending evolution of a complex organ, when it depends on a reduced part, is therefore not impossible (we can suppose, for instance, that the secondary ventrals of teleosts will return in the future to their original condition through the complete disappearance of the clavicular ligaments).

In the case of a nonreduced part, whose form has, however, changed during ascending evolution, the indestructibility of the past again does not exist in the strict sense, the nonreduced part being able to change its form again by a new progressive evolution, although the original condition of this part, and consequently the original condition of the organ in question can not be reestablished. The pelvis of *Triceratops* may be taken as an example. The postpubis of this pelvis exists in a very rudimentary condition, and as rudimentary parts tend to disappear, the postpubis certainly would have disappeared if *Triceratops* had lived long enough. It is therefore only its recurved ischium, very different in form from the ischium of its distant tetrapod ancestors, which was able to prevent *Triceratops* from recovering its original pelvis.

Finally, if there is an ascending evolution of nonreduced parts (pelvis of *Stegosaurus*) it is the change of function which saves these parts from a regressive evolution; the indestructibility of the past does not exist here either. And it is clear that the same reasoning is also applicable under the third law to the evolution of a complex organ.

To sum up: The irreversibility of the evolution of a complex organ depends entirely on the irreversibility of the evolution of the reduced or nonreduced individual parts which enter into its composition, and the second and third laws are not without exceptions in this respect any more than the first; as we have seen, it is the germinal base of the first law which underlies the entire subject.

As I said at the beginning, most naturalists know Dollo's first law only. This is only a part of his general law, although the most important and most certain part.¹ This general law, in spite of the possible exceptions, has an extraordinary importance for biological philosophy and evolutionary philosophy in general. Dollo will al-

¹ Besides the law of irreversible evolution Dollo has formulated (see Dollo, 4, p. 165) two other laws—that of discontinuous evolution (before H. de Vries) and that of limited evolution. In his subsequent writings Dollo has only rarely touched on these two other laws (on the law of limited evolution see Dollo, 7, p. 9, Dollo, 8, p. 813 and p. 820, Dollo, 9, p. 131; on the law of discontinuous evolution see Dollo, 5, rem. (66), p. 120; Dollo, 7, rem. (11), p. 9; and Dollo, 17, pp. 139–140).

ways be regarded, like Cuvier before him, as the founder of a great law of the organic world.¹

LITERATURE.

1. L. Dollo, Cours autographié sur l'évolution du Squelette des Vertébrés. Leçons faites à l'Institut Solvay (Université de Bruxelles) en 1891-2.
2. — Sur l'origine de la nageoire caudale des Ichthyosaures. *Bulletin de la société belge de Géologie, de Paléontologie et de Hydrologie*, vol. 6, 1892, Procès-verbaux, pp. 167-74.
3. — Sur la morphologie des côtes. *Bulletin scientifique de la France et de la Belgique*, publié par A. Giard, Paris, vol. 24, 1892, pp. 113-29.
4. — Les lois de l'évolution. *Bulletin de la soc. belge de Géol.*, etc., vol. 7, 1893, Procès-verbaux, pp. 164-6.
5. — Sur la phylogénie des Dipneustes. *Bulletin de la soc. belge de Géol.*, etc., vol. 9, 1895, Mémoires, pp. 79-128.
6. — Les ancêtres des Marsupiaux, étaient-ils arboricoles? *Miscellanées biologiques dédiées au Prof. A. Giard*, Paris, 1899, pp. 188-203.
7. — Sur l'origine de la Tortue Luth (*Dermochelys coriacea*). *Bulletin de la société royale des sciences médicales et naturelles de Bruxelles*, 1901, separate, pp. 1-26.
8. — Sur l'évolution des Chéloniens marins (Considérations bionomiques et phylogéniques). *Bulletin de l'Académie royale de Belgique*, Classe des Sciences, 1903, pp. 801-50.
9. — Un nouvel opercule tympanique de *Platystrophia* (Mosasaurien plongeur). *Bulletin de la soc. belge de Géol.*, etc., vol. 19, 1905, Mémoires, pp. 125-31.
10. — Les Dinosauriens adaptés à la vie quadrupède secondaire. *Bulletin de la soc. belge de Géol.*, etc., vol. 19, 1905, Mémoires, pp. 441-8.
11. — Le pied de l'Amphiprovierra. *Bulletin de la soc. belge de Géol.*, etc., vol. 20, 1906, Procès-verbaux, pp. 166-9.
12. — Nouvelle note sur les reptiles de l'Eocène inférieur de la Belgique et des régions voisines (*Eosuchus Lerichei* et *Eosphargis gigas*). *Bulletin de la soc. belge de Géol.*, etc., vol. 21, 1907, Procès-verbaux, pp. 81-5.
13. — Les Ptyctodontes sont des Arthodères. *Bulletin de la soc. belge de Géol.*, etc., vol. 21, 1907, Mémoires, pp. 97-108.
14. — Les Téléostéens à ventrales abdominales secondaires. *Verhandlungen der k. k. zool.-botan. Gesellschaft in Wien*, vol. 59, 1909, pp. 135-40.
15. — Les poissons Volliers. *Zoologische Jahrbücher, Abtheilung für Systematik*, vol. 27, 1909, pp. 419-38.
16. — La Paléontologie éthologique. *Bulletin de la soc. belge de Géol.*, etc., vol. 23, 1909, Mémoires, pp. 377-421.
17. — Les Céphalopodes adaptés à la vie nectique secondaire et à la vie benthique tertiaire. *Zoologische Jahrbücher*, Supplément vol. 15 (Festschrift, J. W. Spengel, vol. 1), 1912, pp. 105-40.
18. — Globidens Fraasi. *Archives de Biologie*, vol. 28, 1913, pp. 609-26.
19. — *Podocnemis congolensis* et l'évolution des Chéloniens fluviaux. *Annales du Musée du Congo Belge*, Bruxelles, 1913, pp. 49-65.
20. A. Giard, Les tendances actuelles de la morphologie. *Revue scientifique*, 1905, pp. 171-2.

¹ To the list of Dollo's writings on the law of irreversible evolution I am adding the titles of some other papers (most of them already cited by Dollo) whose authors have discussed or applied this law. Among these treatises the important book by O. Abel, *Grundzüge der Paläobiologie der Wirbeltiere*, 1912, deserves special mention because it contains nearly all the examples cited by Dollo and many others besides. Dollo's law is discussed, pp. 616-618.

21. G. v. Arthaber, Beiträge zur Kenntniss der Organisation und der Anpassungserscheinungen des Genus *Metriorhynchus*. *Beiträge zur Paläontologie und Geologie Oesterreich-Ungarns und des Orients*, 1906, p. 301.
22. CH. Déperet, Les transformations du monde animal, 1907, pp. 243-4.
23. F. v. Huene, Die Dinosaurier der europäischen Triasformation, 1908.
24. A. Handlirsch, Die fossilen Insekten und die Phylogenie der rezenten Formen, 1906-8, vol. 2, p. 1328.
25. H. F. Osborn, The Age of Mammals, 1910, p. 34.
26. K. Diener, Paläontologie und Abstammungslehre, Sammlung Götschen, pp. 98, 110-14.
27. O. Abel, Grundzüge der Paläobiologie der Wirbeltiere, 1912.
28. W. B. Scott, A History of Land Mammals in the Western Hemisphere, 1913.
29. R. S. Lull, Organic Evolution, A Textbook, 1917, p. 280 and p. 572.

THE FUNDAMENTAL FACTOR OF INSECT EVOLUTION.¹

By S. S. CHETVERIKOV.

[With 1 plate.]

The question of how this evolution traveled, which factors directed it along the course that led insects to their present height of organization, is of deep interest to every entomologist.

Insects appeared on the earth very long ago. Beginning with the middle of the Paleozoic era—namely, the Carboniferous period—the earth's crust contains undoubted traces of insects, principally impressions of wings, and indications of insects exist even in the earlier epochs. And thus, in course of this colossal interval of time, an interval the greatness of which is beyond the limit of human understanding (be this interval 30,000,000 or 60,000,000 years, the impression on the mind will not be different), the process of evolution of the insect forms continued unabated—a process which brought them to the present stage. The tremendous development attained by insect life on earth is best shown by the following few figures. By 1907, 384,000 species of insects were described and named. An annual average of about 6,000 species is being described since then, a number which shows no tendency to diminish; on the contrary, as Europeans penetrate into tropical countries, this number is showing decided increase. Thus, all agree that the number of species of insects on the earth must be expressed by a number of at least seven figures. But, whichever the number we finally agree upon, whether that of 10,000,000 species by Riley, or the more modest figure of 2,000,000 by Sharp, one fact remains certain—namely, that the number of species of insects is at least six times that of species of all the other animals put together. And, if we recall that the number of individuals of each species of insects is on the average many times greater than that of other species of animals (excepting Protozoa), the colossal development of animal life in the form of entomons will become fully evident.

What is the cause of this? What is there in the insect that gave it the capability of occupying this exclusive position in the animal

¹ Translated from the Russian by Jacob Kotinsky, Branch of Forest Insects, Bureau of Entomology, U. S. Dept. of Agriculture, from Bull. Soc. Ent. Moscow, Vol. I, p. 14, Nov. (15) 28, 1915.

world? To answer this question, let us look a little into the past of our planet and raise, as much as nature will permit us, the curtain that shrouds its past history.

In looking into the past and present of the animal world of the terra firma we perceive one fact—two types of animals are striving for dominance. These two types are the vertebrates and the arthropods. True, parts of both types (fishes and crustaceans) remained in the water, in their native medium, but in the present case they will not interest us. But in the evolution of insects (as well as the other classes of terrestrial arthropods) on the one hand and terrestrial vertebrates on the other we see a striking contrast; we have before us one of those characteristic instances full of deep significance, where nature, in aiming for the same goal, proceeds and attains it by means of two opposite routes.

If this goal is assumed to be the protection of the species in the struggle for existence, what are the paths along which the vertebrates and the insects traveled? These roads are hidden from us in the deep mystery of the past ages, and only scant, fragmentary, and scattered data for study are given us by the paleontological discoveries.

The first impression we get from these data is that in early geological epochs the vertebrate world was incomparably larger, more massive than in the contemporary; that the type of vertebrates appears to be degenerating, growing smaller.

Indeed, a whole series of gigantic forms which previously populated the earth has completely disappeared from its face: all the 50-foot long *Brontosauri*, *Mastodonsauri*, elephant-like *Dinotheres*, *Mastodons*, and many, many others died out, and the vast majority of contemporary vertebrates can not compare with them in size of body. However, on closer study we will note a different aspect. We will see that none of these vertebrate giants are the ancestors of the present forms. On the contrary, these are all forms which are always extremely and one sidedly specialized, adapted to definite and, doubtless, limited conditions of existence. And what is no less important, to which I wish to call special attention, is the fact that these gigantic forms appear as if they always conclude a series of links of a chain of successive forms, at which it suddenly breaks. These chains usually begin with *small* forms, with primitive peculiarities of structure and only as specialized characters accumulate does the size of the animals grow until it attains gigantic proportions and extreme specialization, and then the power of adaptation to changed conditions of existence seems to disappear and the entire chain of forms closes its earthly existence. For illustration I will present a few examples.

The class Amphibia at first appears in the lower carboniferous deposits as small salamander-like forms, *Branchiosaurus*, which belong to the subclass *Stegocephali*. But in the triassic we come across such

gigantic forms as *Mastodonsaurus*, of which the skull alone was about 5 feet long. But with these gigantic forms the entire subclass of *Stegocephali* dies out.

The class of reptiles appears in the Permian period, and is here at first represented by small primitive forms, which rarely exceed a half meter in length (*Palaeohatteria* of *Rynchocephalia*, 50 cm. long; *Seymouria* of *Anomodontia*, length of skull 10 cm.). Only in the mesozoic, as the specialization of the first primitive characters develops, do larger and larger and finally gigantic forms occur.

Even in orders this relation may be followed out. Thus, in the order *Sauropterygia* the most primitive is the small *Lariosaurus* (25-100 cm. long) and its highest specialization the order attained in the huge *Plesiosaurs* and *Pliosaurus*, the skull of which is almost 1.3 m. long. The order *Dinosaurus*, which always astounded human imagination by the abundance of gigantic, colossal, and most curious forms, appears at first in the Triassic in the form of comparatively small and primitive forms. Only later, in the upper Jurassic and in the chalk, do the *Dinosauria* attain their greatest specialization and dimension (*Brontosaurus* 17 m. long, upper Jura.; *Stegosaurus*, 9 m. long, upper Jura.; *Iguanodon*, almost 10 m. high, upper Jura. chalk; finally, *Triceratops*, from the upper chalks with the largest skull that ever existed on dry land, a length exceeding 2 m.). But after that all of these curious creatures rapidly die out.

The mammalia also began their existence with insignificant sizes (*Amphilestes*, *Triconodon*, and others), the length of which scarcely exceeded that of a rat. But specialization proceeded gradually and parallel with it also increase of size until there appeared such colossal and in some respects highly specialized forms as *Dinotherium*, *Mastodon*, mammoths, elephants, whales, etc.

But enough of examples. It seems to me enough of these are given to have the assertion I made above cease to appear as strange as it might have seemed at first. The first impression, that the evolution of the vertebrates proceeded from primitive large forms to small ones, is false. On the contrary, we see the exact opposite: Primitive forms are small and the massiveness of the animal body grows only in course of evolution and specialization. If we should now wish to answer the question made above—i. e., by what path did the vertebrates travel toward self-preservation in the struggle for existence?—the answer will now be clear. It is the path of gradual perfection, parallel with the accumulation of strength. This is the path of open, direct force, but at the same time of honorable struggle. The vertebrate faced danger; it did not run from it, did not hide, and only developed its strength and power in the process of perfection for the purpose of meeting the enemy. The herbivor increased its body in order to place its mass in opposition to

the smaller carnivor; the carnivor increased its strength in order to be in condition to overpower the larger prey which was slipping away from it. And thus continued step by step the struggle, a continuous open struggle, which resulted in the gigantic and highly specialized forms. But conditions of existence changed and the massive specialized animals were not able to obtain the necessary plasticity and adaptability, and died out, completing in themselves the chain of development of separate groups. Such is in general the process of evolution of the external appearance of the type of vertebrates.¹

We will now pass to the insects. To keep abreast of the vertebrates, by developing the massiveness of form, they were evidently unable to do. The very brevity of their life cycle with the usually rapid cessation of growth gave them no hope of conquering even a modest position for themselves among the increasingly developing vertebrate classes. It would seem their fate was doomed beyond hope. But in the struggle for existence nature recognizes no honorable or dishonorable means; all of them are good if they lead to the purpose, and where nothing can be taken by force she takes things by the aid of trifles, converting these trifles into a mighty power. If the struggle can not be direct it becomes necessary to dodge it. And thus, with this method, diametrically opposed to the preceding, the evolution of insects proceeded.

The world is occupied by large, ponderous vertebrates, engaged in a keen struggle with one another, and to keep up with them there is absolutely no possibility; but everywhere among them there remain small free nooks, whither it is useless for the heavy ponderous vertebrates even to think of penetrating. It is thither that the insects turned. Just as gravel, then sand and dust, more and more firmly fill the free spaces between piles of coarse stone, so the hordes of insects, innumerable as sand, small as dust, more and more completely fill the crevices left by the vertebrates. And there are many of these nooks, and the smaller the form the more room there is for it.

But if what was just said is true, paleontology should confirm it. However delicate, however small the body of the insect, yet under favorable conditions it still left its impression in the thin ooze of the filled basins, and the more than 7,600 species of excavated insects (Handlirsch, 1907) tell us that among them we can seek and should find a confirmation of our thought if it agrees with the truth.

Insects (evidently) started existence in the lower stratum of the Upper Carboniferous era—i. e., in the middle of the Paleozoic—and already toward the end of that era they have attained considerable development, as shown by the 884 species of insects found there.

¹ Of course, we can not consider the above outlined process of evolution as inevitable for all terrestrial vertebrates. Many departures from it could be found. I aimed to give only the general scheme of the process which seemed to me typical for the group of animals under consideration.

If we look at any table (as in Handlirsch) showing the interrelation and evolution of contemporary and fossil insects we will see that almost all Paleozoic orders are extinct. We will also see that the majority of them barely pass out of the Paleozoic period. But, from the evolutionary point of view, the extinct orders are a direct contrast to the majority of extinct orders of vertebrates. These latter became extinct because in their specialization they had come to such a pass from which there was no outlet. The Paleozoic orders of insects, however, are all *Proto* orders (*Protorthoptera*, *Protodonata*, *Protohemiptera*, etc.), and the most ancient order of this period is *Palaeodictyoptera*, an order which embodies in itself all the imaginable most primitive characters of a winged insect.

These orders became extinct not because they were extremely specialized, but because they evolved in the Mesozoic and gave rise to more perfect, better adapted forms which replaced them. And thus if we could get a glimpse into that world to see how these primitive insects lived and how they looked it would help greatly to solve our problem.

If we were to turn to the authority on this subject, to the above-mentioned Vienna savant, Anton Handlirsch, with the request to picture to us the world of Paleozoic insects he could have hardly answered us better than we find it stated in his comparatively recently issued book on fossil insects.¹ This statement is so interesting that I permit myself to quote it in translation:

To our eye, which is accustomed to see usually delicate and extremely variable forms of insects around us, the character of the Paleozoic form of insect fauna should appear very unusual. The vast majority of species of those days exceeded by many times the dimensions of their contemporary progeny, while small forms are entirely absent in the ancient formations, although, as is evident from the Mesozoic deposits, they are capable of preservation not worse than the large ones * * *. In the middle of the Upper Carboniferous period the forest swamps of our areas were populated with cockroaches about as long as a finger, dragon-fly-like creatures with a wing spread of about 2½ feet, while insects that resemble our mayflies were as big as a hand. Heavy, clumsy forms, adapted more for short flits rather than true flight, inhabited the shores of streams and the forest clearings; the ancestors of our grasshoppers, crickets, and cicadas, our flies, ants, and bees passed their monotonous, cheerless life in deep silence, wholly devoted merely to the coarse question of nourishment and the elementary functions of reproduction * * *. Only toward the end of the Carboniferous period and later in course of the Permian period, simultaneously with the dying out of the disappearing, primitive group (*Palaeodictyoptera*), do somewhat more highly organized forms appear and we notice at the same time a diminution in their average dimension.²

A truly characteristic picture, not without some mystic greatness.

In the accompanying illustration (pl. 1) we see a greatly ($\times 4/7$) diminished restoration of one of the insect representatives of that

¹ Anton Handlirsch, — Die fossilen Insekten und die Phylogenie der recedenten Formen. Leipzig, 1906–1908.

² I. c., p. 1150; the italics are mine.

age: *Meganeura monyi* Brongn., order *Protodonata*. Alongside of it (lower right), reduced to the same scale, is its contemporary progeny, *Aeschna grandis* L. What a pitiful pigny it is and its specific name (*grandis*) sounds like such a mockery.

Such are the giant Paleozoic insects.

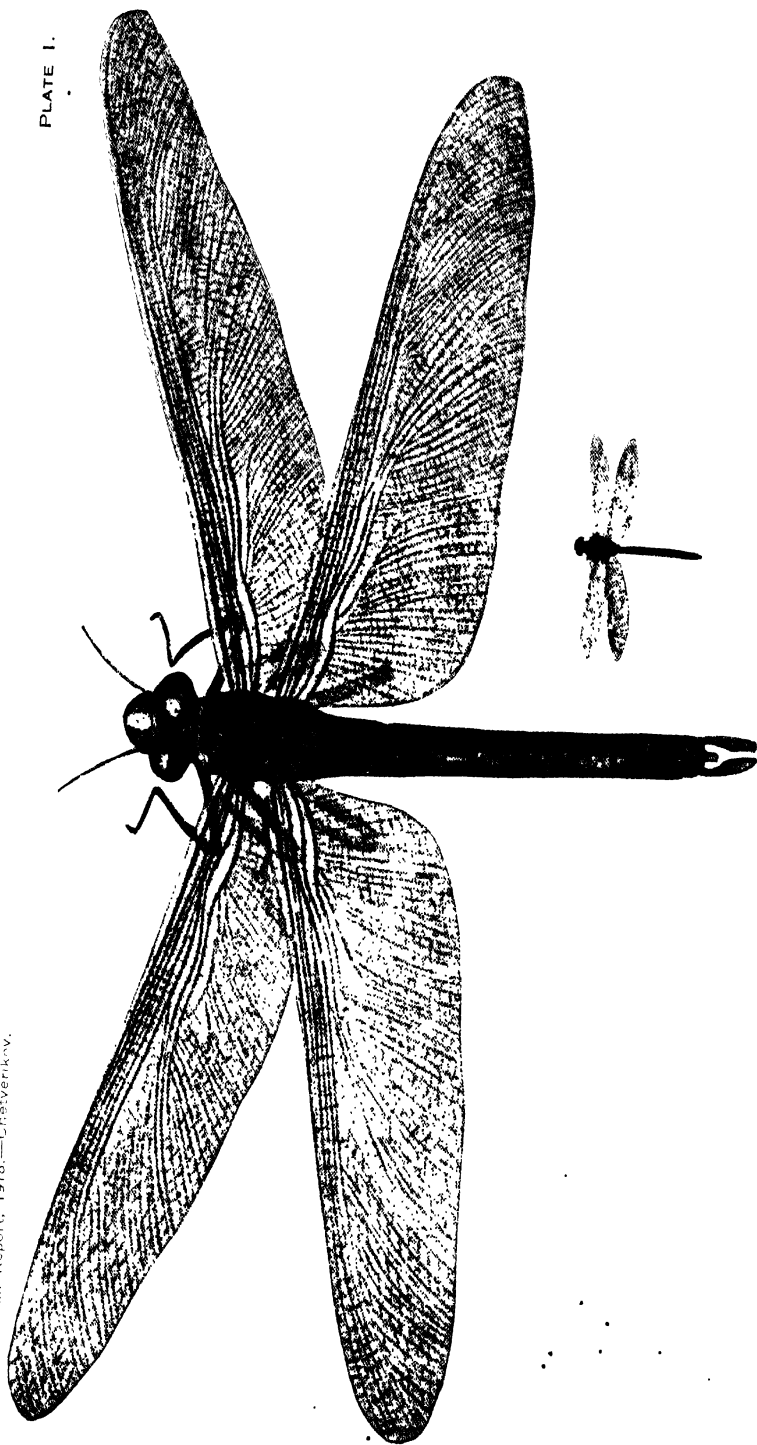
Handlirsch's conclusion that the existence of gigantic forms is explainable by the fact that they lived in a tropical climate is, in my opinion, entirely wrong. I cheerfully admit that in those remote times the climate of the center of contemporary France, where most of the excavated insects lived, might have been tropical, but we have absolutely no proof that this has any causative relation to the large size of the Paleozoic insects.

Handlirsch himself admits that myriads of extremely small forms, the like of which did not exist in the Carboniferous epoch, exist in the present tropics alongside of the larger ones (though still not as large as the Paleozoic). I am firmly convinced that the question here is not of climate, but of the fact that here we have only the beginning, the dawn of insect evolution.

And now we pass over to the Mesozoic. Here the general appearance of the insects changes very abruptly. All contemporary orders and even many of the contemporary families have their representatives there. I will not stop to enumerate; I will merely indicate that insects with complete metamorphosis appear for the first time in the Mesozoic. If we compare the Mesozoic fauna with that of the Paleozoic just described, and then with the contemporary, the first will be found to contain probably more in common with the latter than with the extinct giants that inhabited the Carboniferous landscape. And alongside of the already quite definite specialization in the Mesozoic forms there appear also small, inconspicuous species which attain sometimes barely 3 millimeters in size, but their impressions are still preserved quite clearly.

I call attention to another fact which is associated with the same evolutionary tendency of insects: Four of the contemporary orders (*Coleoptera*, *Lepidoptera*, *Hymenoptera*, and *Diptera*) have developed particularly rapidly in the geological epoch nearest to us. It also appears that just these four orders are particularly rich in small forms. This fact tells us clearly that the evolution of forms, directed towards a diminution in size of body, leads in insects to a rapid development of the orders mentioned. The new forms do not crowd the old ones out; they merely take that which the old ones for some reason were incapable of utilizing. On the other hand, in those orders like the dragon flies and *Orthoptera*, for instance, in which, by virtue of some inherent causes, the process of diminution developed slowly, the entire evolution also proceeds in a slow tempo,

PLATE I.



A. *MEGANEURA MONYI* (BRONGNIART).
B. *AESCHNA GRANDIS* L.
Both at natural size.

and some of them are already approaching the end of their earthly existence.

What cause, then, what factor, started the vertebrates and insects on these two diametrically opposite roads of evolution? What peculiarity of structure of their organism in one case (in the vertebrates) hinders their excessive diminution, admitting at the same time almost unlimited external increase, while in the other case (in insects) diminution is almost unlimited?

However great the difference and variation in the body structure between vertebrates and insects, still the majority of their organs give us no clue to the solution of the problem we proposed. Neither the differences in structure of the alimentary canal, nor of the musculature, the heart, the nervous system, nor any of the other soft internal organs, can explain to us why evolution in the direction of such external diminution was possible in insects and entirely inaccessible to the vertebrates. Only on passing over to a study of the skeleton do we find in the two groups such sharp, characteristic, and common differences which give a key to the understanding of the diametrically opposite paths of their evolution. Saying nothing about the chitin of insects which, owing to its simultaneous hardness and elasticity, represents an ideal skeletal material, the very fact of the transfer of the skeleton of insects to the surface, the periphery of their bodies, appears, in my opinion, to be the most essential moment which determined their evolution.

I will not dwell on the fact that a continuous external skeleton is the best means of protection against the influence of the external medium, which is especially important for small forms, since the relation of the circumference of their body to its surface is in them particularly unfavorable. The purely mechanical peculiarities of the internal as well as the external skeleton are of great importance to us.

In order to explain this question more precisely we will turn to the accompanying illustration (fig. 1). Above is represented a graph of the exoskeleton of, let us say, some extremity, when the diameter of the inner area is $\frac{4}{5}$ of the outer diameter. Below we have two graphs with an internal skeleton arranged along the axis of the extremities. If we now turn to the theory of resistance of materials, we will find there the following data: The modulus (i. e., the power) of resistance to bending (and in the given instance it is just this form of resistance that interests us) in a solid cylinder, and in a hollow one is expressed by the following two formulae:

$$W = \frac{\pi D^3}{32} \text{ and } W_1 = \frac{\pi (D_1^4 - d^4)}{32 D_1}.$$

W and W_1 are the respective moduli;

D is the diameter of the cross section of the cylinder;

D_1 is the outer diameter of the cross section of the hollow cylinder; and

d is the diameter of the cross section of the inner area of the hollow cylinder.

Utilizing these two formulae we may get, by aid of the most elementary algebraic calculations, which need not be made here, the following two interesting conclusions:

1. If we assume that an extremity with the central skeleton (lower left figure) has the same cross section as an extremity with an outer

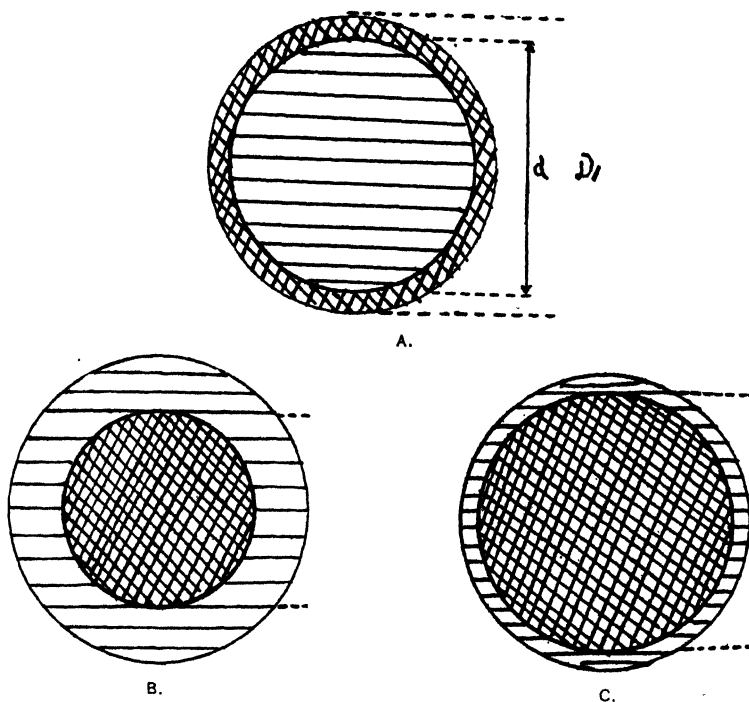


FIG. 1.—Graphs of cross sections of skeletons, of limbs for instance. A, exoskeleton with diameter of internal area (d) = $4/5$ of the external diameter (D). B and C, endoskeletons.

skeleton (upper figure), the areas of the cross section of the skeleton and muscles being equal in both figures, then the extremity with the central skeleton will appear to be almost three times (2 and $11/15$) weaker than the one having a peripheral skeleton.

2. If we calculate the diameter that the cross section of the central skeleton should be in order that, with the same outer diameter of the extremity, it should be equally strong in both cases, we will get the third figure (lower right figure). It turns out that the skeleton has to be colossal: Its diameter must be 84 per cent of the diameter of the whole cross section, so that only an insignificant peripheral layer

is left for the musculature, which is, of course, especially unsuited for a massive, bony skeleton.

We thus see that in both instances there is a decided and tremendous advantage in the insect skeleton. It is only, thanks to these advantages of their external skeleton, that insects were able to develop those small, slender, harmonious, and exquisite forms, the perfection of which we so often admire and whither the vertebrates with their heavy, clumsy endoskeleton were, of course, unable to follow them. And if we add the fact that the exoskeleton represents besides an endless field for the development of purely external characters, then the great variation of contemporary insects should no longer surprise us. But, of course, these forms could develop only gradually, by means of a long and slow evolution, and this is why we do not meet them among the early primitive, cumbersome, and clumsy Carboniferous forms.

We have reached the end of our thesis. If we now return to the question with which we began as to the fundamental cause of the opposite direction of the paths of evolution of vertebrates and insects we will find, it seems to me, but one answer: The cause is, the presence in insects of an outer chitinous skeleton, owing to which they were in a position, by continuously diminishing the dimension of their body, to conquer for themselves an entirely independent place among the other terrestrial animals, and not only to conquer it but to increase in an endless variation of forms and thereby acquire a tremendous importance in the general economy of nature. Thus their insignificance became their power.

THE PSYCHIC LIFE OF INSECTS.¹

BY E. L. BOUVIER.

INTRODUCTION.

The insects are animals which seem to defy our imagination by the strangeness of their forms and the surprising character of their habits. In his "War of the Worlds," Wells, the fiction writer, surprises us with his belligerent Tripods who sweep down as conquerers on our planet, where they exterminate and terrify unhappy humanity. This flight of the imagination appears to exceed all reason, but how far does it not fall short of that which Nature herself provides for our astonishment in the realm of the Articulates! Here, it is true, we do not meet with Tripods, but the Hexapods or Insects have invaded the entire terrestrial domain, where they make their power terribly felt; the Octopods or Arachnids share this domain both with the Insects and with the Myriapods, these latter often possessing more than a hundred pairs of legs; while in the water swarm the Crustaceans which rival the Myriapods in the number of their appendages. And what do the organs with which Wells endows his Tripods amount to when compared with those which serve as arms or ornaments to a host of Articulates; when compared with the enormous pincers of crabs and lobsters, with the serrated sword-like beak which projects from the forehead of shrimps, with the wonderful trocar at the end of the abdomen in female Hymenoptera, with the overgrown horns which rise from the head and thorax of not a few Scarabaeids, with the many spines bristling on the body of the thorny spiders, or with the exceedingly elongated legs which give to the Myriapods of the genus *Scutigera* their swift gait and terrifying aspect?

The habits of these animals are just as puzzling as their shapes. What is the meaning of the horrible courtship of spiders and mantids, where the female's response to the embrace of her mate is cannibalism? What must we think of the predatory wasps which paralyze with dagger thrusts the victims intended for their larvæ? What of the Brachonids and Ichneumons, which deposit their eggs either on or in the body of other insects? What, above all, must we think of

¹ A translation by permission of the Introduction and Conclusion of "*La vie psychique des Insectes*," by E. L. Bouvier; published by E. Flammarion, Paris.

the larvae issuing from these eggs and scientifically devouring their host, taking pains to leave intact until the very last his most vital organs? The orb-weaving spiders have no peers in the art of weaving. They know how to fasten marvelously regular webs between the branches of trees, how to pass over rivers on bridges of floating threads, and, when still young, how to use similar threads to take flight through the air as real aeronauts. The sacred Scarab fashions into a pear-shaped ball the oily dung of sheep and into a perfect sphere of foodstuff the coarse excrement of horses; and certain wasps of the genus *Eumenes* mold tempered earth into pottery of the most charming design. Face to face with these phenomena which surprise him, man wonders and tries to understand, but especially does he endeavor to protect himself against these strange creatures among which he finds more enemies than aids; prolific and multi-form the minute *Phylloxera* has succeeded in destroying his vineyards; voracious and migratory the bulky locusts advance in numberless legions to lay waste his crops; various flies and gnats sting and infect his cattle. And he himself does not escape the virus secreted by these terrible pests; mosquitoes threaten him with malaria in the vicinity of marshes and the *Glossinas* with sleeping sickness in the damp and shady jungles of the African tropics; fleas bring him the germs of plague, and filthy lice that of the typhus fever which claimed so many victims in the East at the beginning of the present war.

What a contrast with the vertebrates, which form the other highest point of the animal kingdom! No doubt among the latter there exist cruel and voracious species; some of them are openly hostile to us, and many are remarkable for their instincts and their skill. But where do we find the excessive variety of forms and the oddity of habits which are the heritage of the *Articulates*? Georges Maeterlinck gives us a poetic version of this striking contrast: "The insect," he says, "does not belong to our world. The other animals, even the plants, notwithstanding their mute existence and the great secrets which they jealously guard, do not seem wholly strangers to us. In spite of everything we have a certain feeling of terrestrial kinship with them. They may surprise, nay, astonish us, but they fail to upset the very foundations of our concepts. The insect, on the other hand, displays something that seems incongruous with the habits, the morals, the psychology of our globe. Apparently it comes from another planet, more monstrous, more vigorous, more demented, more atrocious, more infernal than ours. Vainly does it seize upon life with an authority and a fecundity unequaled here below; we can not accustom ourselves to the idea that it is part of the scheme of that nature of which we fondly believe ourselves to be the favorite children. With this amazement and this failure to understand is mingled,

no doubt, a certain instinctive and profound feeling of dread imparted by these beings so incomparably better armed and equipped than ourselves, these containers as it were of compressed energy and activity which we vaguely feel to be our most mysterious enemies, our final competitors, and perhaps our survivors."

Everything concerning these animals is surprising, even when, in the present stage of their mental evolution, they seem to come near us and to engage in activities, such as we frequently observe among the social species, which might well be considered as human. We are perplexed at the foresight of harvesting ants, at the care other ants take of their herds of plant lice, at the horticultural skill of the fungus-growing species and at the specialization of labor which reduces certain workers among the Myrmecocysts to the condition of honey-pots. We prize so highly all our own aptitudes as to believe that they are unequalled, even when inspired by the least commendable motives. Though bellicose ourselves, we think it strange that beehives or ants-nests should engage in warfare. At times we revert to barbarism by reducing our enemies to slavery, yet we exclaim with surprise at the habits of slave-making ants.

It is the fact that these wonderful analogies are well calculated to emphasize the contrast between the world of the Articulates and our own. We feel that the psychic evolution of these animals is no less peculiar than their structure, and that they are never so widely separated from us as when they appear to resemble us most closely. The old anthropocentric school has passed away; we no longer attempt to understand insects by comparing them to man, we rather try to grasp the mechanism that allows these animals to evolve mentally and to develop modes of action which appear human.

Such was our object in writing this book. The sources from which we could draw in compiling this work were numerous, but we have not made use of them all, because many are lacking in the required scientific accuracy. Moreover, ever since the work of Loeb and Jennings research in animal psychology has been directed along a fruitful path, where we ourselves were happy to follow the footsteps of these biologists and their many disciples, such as Bohn, Pieron, Rouband, Turner, etc. Much attention has been paid also to the work of biological observers from Réaumur (*Mémoires pour servir à l'histoire des Insectes*) to Fabre (*Souvenirs Entomologiques*), where abundant information may be gleaned on every page. In this company, where France occupies such an honorable place, we wish to call especial attention to Commander Ferton, whose work is remarkably rich and exact. To my dear pupil, George Bohn, special acknowledgment is due for the value of his numerous papers and for the originality of his two books, "*Naissance de l'Intelligence*,"

and "*Nouvelle Psychologie Animale*," as well as for the material contributed by him toward the preparation of the present study.

CONCLUSION.

In ordinary speech, the word "instinct" stands for all the hereditary and automatic revelations of activity, from simple tropisms to the most complicated outward manifestations of individual memory. Instinctive acts are stereotyped, being ever the same when responding to stimuli of the same nature, and almost always adapted to their object, although not resulting from previous experience on the part of the individual. To define them more precisely is impossible, for they are varied and complex, overlapping one another and often becoming so confused as to render difficult the tracing of their limits. Nevertheless, we should not place them all on the same level and attribute to them all a common origin. Tropic reactions are due to the properties of living matter, rhythms presuppose an organic memory, and hence a period of education, ancient or recent; but this apprenticeship is purely mechanical and dependent upon the stimuli that produce it.

Apprenticeship has its part also in those manifestations of memory belonging to the species which play such an important part in the behavior of articulates. This kind of memory presents a character of distinct superiority, inasmuch as it was made effective for the race by the distant ancestors of the individual in the guise of a choice between the various possible responses of differential susceptibility. Choice, of a remarkably intellectual nature, is even more noticeable in the instinctive manifestations of individual memory. The animal, endowed with well-developed senses and nervous system, not only reacts to new necessities by new acts, but associates the stored impressions of new sensations and thereby appropriately directs its further activities. Thus, by an intelligent process, new habits are established, which by heredity become part of the patrimony of instinct, modifying the latter and constituting elements essential to its evolution. Of these instincts acquired through an intelligent apprenticeship Forel was led to say that they are reasoning made automatic, and it is to them particularly that we may apply the idea of certain biologists that instincts are habits which have become hereditary and automatic. Probably all superior instincts at first had this intellectual quality. This certainly is true of all such as originated from more or less slowly acquired habits; it seems to be the rule as well with instincts due to mutations. It stands to reason that, whether they result from a sudden psychic change or from a sudden organic modification, these instincts must always be preceded by some intelligent period of education, during which they

become perfected, in order to be handed on to posterity and to assume the character of true instincts.

Here, then, we are confronted with several classes of instinctive acts, which differ not only in origin but also in intellectual characteristics. No doubt they are linked together by many intermediate manifestations, and in the animals with which we are now concerned they often blend the one with the other or even with the reflexes, on account of the profound differentiation of nervous and sensorial centers. It is, nevertheless, very difficult to consider them as manifestations of a special faculty which we would fain place on the level of intelligence by calling it instinct. The name instinct justly applies to certain forms of activity which are innate and automatic, but these forms proceeded in diverse ways from the vital energy which is the source of all organic activity, and the highest of them, which are at the same time the most striking ones in the animals here studied, were originally acts more or less requiring the exercise of true intelligence on the part of species and individuals. Intelligence has no part in the development of the instinct that draws nocturnal *Lepidoptera* toward the light, nor has it doubtless anything to do with the rhythms through which organic memory manifests itself. But intelligence it is that regulates by appropriate selection all manifestations of race memory; intelligence again, in the sundry forms of association and individual memory, that puts together the most complicated mechanisms of instinct.

Instincts are of various kinds. If, by the word instinct we understand not any one special faculty, but the complex of all the instincts, namely, the innate automatism regardless of its origin, we can say with Bergson that instinct and intelligence "are not things belonging to one and the same order," that they "diverge in direct ratio of their development," but that "they never become completely separate." They are both "opposites and complements" and they assist one another. "On the one hand, indeed, the most perfect instincts of the insects are accompanied by certain gleams of intelligence, be it only in the choice of place, time, or material of construction. When, by exception, bees build their nest in the open, they invent arrangements which are new and in the true sense intelligent to meet the new conditions. On the other hand, intelligence has still more use for instinct than instinct has for intelligence, since the ability to work up raw material presupposes in the animal a superior grade of organization, to which it could have arisen on the wings of instinct only." Before such evidence as this Fabre was forced to modify his theory of immutable instinct. "By itself, mere instinct," says he, "would leave the insect disarmed in the perpetual conflict of circumstances. A guide is needed in the midst of this bewildering mêlée. That the insect has such a guide is evident to

a high degree. This is the second domain of its psychic powers. Here it is conscious and susceptible of perfecting by experience. As I dare not designate this rudimentary aptitude by the name of intelligence, a title too noble for it, I shall call it *discernment*." But is discernment in this sense not really a form of intelligence?

Such is the measure in which instinct and intelligence are combined in animals. If, following Bergson, we admit that consciousness "is proportional to the power of selection at the animal's disposal," it will be quite evident that consciousness must be particularly obscured in all purely instinctive acts, but that on the contrary it must accompany all intelligent acts. Bergson, however, regards consciousness in a peculiar light, since he considers it as "life projected through matter," as the common source from which sprang in different directions both instinct and intelligence. This view leads us away from the commonly accepted theory that consciousness must be considered as that inmost luminary which enlightens our actions. It is possible, even probable, that this kind of consciousness exists to a greater or lesser extent in the animals. However, we can not know anything about it, and we believe with Ed. Claparède that "the science of animal psychology may and must scrutinize the problem of the greater or less intelligence of animals without being concerned about their consciousness."

We discern intelligence in its simplest expression wherever we notice a choice between the various alternatives offered by circumstances, and in one of its highest forms wherever we observe that power of invention which, according to Bergson, enables the human race to "manufacture artificial objects, more particularly to make tools with which to make other tools and to vary their fabrication indefinitely." These two extreme forms are naturally connected by a series of links, and we know that the one as well as the other plays a part in the behavior of Articulates. The latter of the two seems, however, to be rather exceptional in our group, showing itself only in the primitive state consisting of the use of foreign bodies as implements. The tool used by *Ammophila urnaria* is a small stone with which the female rams and packs the dirt that closes her burrow. With certain ants of India (*Occophylla smaragdina*) and of Brazil (*Camponotus texter*) the instrument consists of the larva of the species itself. Held between the mandibles of the workers, these larvæ by means of their thread glue and fasten edge to edge the leaves of which the nest is constructed. The implement of the crabs of the genus *Melita*, in the Indo-Pacific seas, is supplied by a delicate sea-anemone. This is held between the pincers of the animal, which probably uses the nettling exudations to paralyze its prey.

Facts of this nature are rare in the world of Articulates, but they have an important significance. The use of the little stone is not yet

a fixed habit with *Ammophila urnaria*, it belongs only to certain individuals more highly endowed than others and is perhaps only accidental even with them. Maybe it will finally pass into the instinctive habits of the species; for the present it belongs to the domain of individual intelligent acts. The crabs of the genus *Melia* are already farther advanced, all the species carry anemones and all exhibit a curious modification of the pincers, the fine teeth having become elongated and needlelike so as to give them a better hold on their guest and tool. That they are adapted to the latter is evident, yet this adaptation is not such that the crab is likely to be in serious danger when it has not its *Actinia*. Many of the *Melias* brought back by explorers are not provided with anemones, and we may believe that the presence of this implement guest is not yet of vital importance to the species of this peculiar genus. The case of the ants which use their larvæ as needles is quite different. With them this singular habit is innate and specific. Though probably acquired through intelligent acts, it now belongs entirely to the domain of instinct in the species among which it prevails. And thus we always come back to that predominating fact of the psychological history of *Articulates*, namely, the transformation of intelligent acts into instinctive acts. The following considerations formulated by Bergson eminently apply to this group:

Among animals, invention is never more than a variation on the theme of routine. Locked up as it is within the habits of its species, the animal succeeds no doubt in broadening these by individual initiative; but its escape from automatism is momentary only, just long enough to create a new automatism; the gates of its prison close as soon as they are opened; dragging the chain merely lengthens it. Only with man does consciousness break the chain.

Man occupies the topmost place in the scale of vertebrates, for, breaking the bonds of instinct, he insures thereby the complete expansion of his intellect. Insects, especially *Hymenoptera*, hold the same dominating position in the scale of *Articulates*, where they are the highest achievement of instinctive life. These two groups represent the actual extremes of the two paths followed by psychic evolution in the Animal Kingdom; the articulates are going toward instinct, the vertebrates toward intelligence. These two courses are quite opposite, but why have they diverged? At the beginning of their evolution, during that far distant epoch when they were differentiating along four main lines (*Echinoderms*, *Molluscs*, *Articulates*, and *Vertebrates*), animals were threatened by a great danger—"an obstacle," says Bergson, "that doubtless almost checked the progress of animal life. There is a peculiarity which we can not help being struck by when we glance at the Paleozoic fauna. The mollusks at that time were more universally provided with shells than those of to-day. The arthropods in general were provided with a carapace.

The oldest fishes had a bony covering of extreme hardness." But "the animal which is shut in a fortress or in a coat of mail is condemned to an existence of half-sleep. It is in this torpor that the Echinoderms and even the mollusks are living to-day. The Arthropods and Vertebrates escaped from it, and on this happy circumstance depends the present development of the highest forms of life.

"In two directions, indeed, do we see the impulse of active life regaining the upper hand. The fishes exchange their ganoid armor for scales. Long before them the insects had made their appearance, having also rid themselves of the armor that once protected their ancestors. In both groups the inefficiency of the protective envelop was compensated for by a nimbleness that enabled them to escape their enemies and also to take the offensive and to select the place and time of the encounter."

These remarks rest on a solid foundation, but they should be modified in one particular which is of paramount importance in the explanation of the structure and the special psychology of the Articulates. These animals have never lost the chitinous armor that protected their primitive ancestors. They have preserved it in its entirety and with greater or less thickness. Coleoptera, crabs, scorpions, and thousand-legs of our times are by no means inferior in this regard to the ancient forms from which they are descended.

As a matter of fact they are covered to-day as in times of yore, with an external skeleton of chitin. That is why Edmund Perrier, in his desire to emphasize their dominant character, has called them Chitinophores. To escape imprisonment within their protective envelope, to acquire the flexibility and mobility necessary to their evolution, they underwent certain superficial modifications. These consisted in the division of the armor into several pieces by means of articular lines, along which the chitin is less thick than elsewhere, thus allowing the pieces to move one upon the other. This is the very way in which they became *Articulates*, at once acquiring agility without losing their protective cover. Naturally such joints were formed wherever the several segments, arranged in a row and constituting the body of the animal, came together. As a result, these segments acquire a certain independence and their uniformity is to a certain extent preserved. Indeed, we see that many Articulates possess a pair of appendages on each segment (Myriapods and the majority of Crustaceans) and that the insects most remote in this regard from the primitive types are still provided with seven pairs of appendages (one pair of antennae, three pairs of buccal appendages and three pairs of legs) not to speak of the modified or rudimentary organs to be seen on the different parts of the abdomen. And the chitinous envelope of these appendages has broken into

joints in the same manner in which the body itself became annulated. Hence the name of *Arthropods* often given to articulate animals.

What a difference from the vertebrates. Their skeleton becomes an internal framework. The organism is thus allowed to attain greater dimensions; the segments are able to fuse to a greater degree and to lose more or less their independence; all of which results in the reduction of the number of limbs to only two pairs.

Now, the relative independence of the segments and the multiplicity of the appendages have as a corollary the differentiation of these structures, each of which plays a special part in the organism. As Bergson remarks, the various appendages of Articulates are as it were natural implements, which differ from each other in structure as well as in function. Their specialization may be carried so far as to have each part of a single organ perform a separate function. This is clearly seen in the bee, in which the first tarsal joint of the hind legs is transformed into a brush, the tibia into a pollen basket, while the two joints, by the contact of their edges, act as pincers which take up the flakes of wax secreted under the abdomen. It is an admirable instrument wonderfully adapted to the performance of its particular tasks. As a general rule, apart from the changes which they may undergo in the course of specific evolution, the appendages of arthropods are unchangeable in the individual and are narrowly adapted to certain purposes; they are the tools for instinctive work, and in this they differ from the less specialized but more generally useful limbs which serve as implements to the vertebrates, at least to the higher vertebrates. With these latter, as Bergson expresses it, the two pairs of limbs "perform functions much less strictly dependent upon their form," acquiring complete independence in man, "whose hand can do any kind of work."

It seems, then, that the extraordinary preponderance of instinctive activity among the Articulates has as its essential reason the differentiation and the multiplicity of the appendages, in other words, the chitinization of the integument and the formation of joint lines which results from it. From the beginning these animals were doomed to use organic instruments, and they made the best use possible of these. Their main psychical task consisted in engraving upon their memory and in instinctively repeating the acts to which these organs were adaptable.

SEXUAL SELECTION AND BIRD SONG.¹

By CHAUNCEY J. HAWKINS.

The place of song in the life of the bird has since the days of Darwin been a question of dispute between the scientists. Darwin was the first to deal with bird song in a satisfactory, philosophical manner. He formulated the theory of sexual selection, which down to the present day is still held by many ornithologists to be the most satisfactory explanation of the use of song as well as the best explanation of its evolution. He maintained that the males possessing the best song would naturally be the choice of the females, and that the song characteristics which had made a male the choice of his mate would naturally be handed on to his offspring—in other words, would become secondary sexual characters. This Darwin called sexual selection in distinction to natural selection, whose operation had a wider scope.

To do Darwin justice, we should state the theory in his own language. Sexual selection "depends on the advantage which certain individuals have over others of the same sex and species solely in respect of reproduction." * * * In cases where "the males have acquired their present structure, not from having transmitted this advantage to their male offspring alone, sexual selection must have come into action." * * * "A slight degree of variability, leading to some advantage, however slight, in reiterated deadly contests, would suffice for the work of sexual selection." * * * So too, on the other hand, the females "have, by a long selection of the more attractive males, added to their beauty or other attractive qualities." * * * "If any man can in a short time give elegant carriage and beauty to his bantams, according to his standard of beauty, I can see no reason to doubt that female birds, by selecting during thousands of generations the most melodious or beautiful males, according to their standard of beauty, might produce a marked effect." "It has been shown that the largest number of vigorous offspring will be reared from the pairing of the strongest and best armed males, victorious in contests over other males, with the most vigorous and best nourished females, which are the first to breed in the spring. If such females select the more attractive, and at the

¹ Reprinted by permission from the *Auk*, vol. xxxv, No. 4, October, 1918.

same time vigorous males, they will rear a larger number of offspring than the retarded females which must pair with the less vigorous and less attractive males. So it will be if the more vigorous males select the more attractive, and at the same time healthy and vigorous females; and this will especially hold good if the male defends the female and aids in providing food for the young. The advantage thus gained by the more vigorous pair in rearing a larger number of offspring, has apparently sufficed to render sexual selection efficient."

Wallace was the first critic of the sexual selection theory. He admits the display of gorgeous colors, the antics and songs of the male bird before the female, as fully demonstrated by Darwin, but he says, "it by no means follows that slight difference in the shape, pattern, or colors of the ornamental plumes are what lead a female to give the preference to one male over another; still less that all the females of a species, or the great majority of them, over a wide area of country or for many successive generations prefer exactly the same modifications of colors or ornament." Thus he rules out the idea that the female makes a conscious choice of the male most highly colored or who is the best singer. But this does not destroy the idea that there may be an unconscious choice. Indeed, Wallace seems to admit this possibility when he says, "As all the evidence goes to show that, so far as female birds exercise any choice, it is of the most 'vigorous, defiant, and mettlesome' males, this form of sexual selection will act in the same direction (as natural selection), and help to carry on the process of plume development to its culmination." If this choice exercised by the female is unconscious rather than conscious, Darwin's theory is not vitally affected. All he is anxious to demonstrate is that the most vigorous bird succeeds in winning the most desirable mate, however the choice may be made, and if he succeeds in this the bird may pass to his offspring his own characters which in succeeding generations will become permanent.

But Wallace goes deeper in his criticism than the mere matter of choice. He attributes the origin of song to natural selection rather than to sexual selection. Darwin begins with sober colors and attributes the gay colors of the males to selection on the part of the female. Wallace starts with the gorgeous colors and declares that the gray colors of the females are due to natural selection. Bright plumage would render the mother bird sitting on her nest conspicuous and make her the easy prey to hawks and other natural enemies. Hence all the highly colored females, through generations, have been destroyed, only the more sober colored birds remaining.

The original brightness has been forfeited by the sex as a ransom for life. Female birds in open nests are similarly colored like their surroundings; while in those birds where the nests are domed or covered, the plumage is gay in both sexes.

The same principle of natural selection may be attributed to the call of birds. "These are evidently a valuable addition to the means of recognition of the two sexes, and are a further indication that the pairing season has arrived; and the production, intensification, and differentiation of these sounds and odors are clearly within the power of natural selection. The same remark will apply to the peculiar calls of birds, and even to the singing of the males. These may well have originated merely as a means of recognition between the two sexes of a species and as an invitation from the male to the female bird. When the individuals of a species are widely scattered, such a call must be of great importance in enabling pairing to take place as easily as possible and thus the clearness, loudness, and individuality of the song becomes a useful character, and therefore the subject of natural selection."

The increase and development of beautiful plumage is caused by the superabundant energy of the male bird.

During excitement and when the organism develops superabundant energy, many animals find it pleasurable to exercise their various muscles, often in fantastic ways, as seen in the gambols of kittens, lambs, and other young animals. But at the time of pairing male birds are in a state of the most perfect development, and possess an enormous store of vitality, and under the excitement of the sexual passion they perform strange antics or rapid flights, as much probably from the internal impulse to motion and exertion as with any desire to please their mates.

So, also, "the act of singing is evidently a pleasurable one, and it probably serves as an outlet for superabundant nervous energy and excitement, just as dancing, singing, and field sports do with us." If superabundant vigor can account for the songs and ornaments of birds "then no other mode of selection is needed to account for the presence of such ornament."

Brooks attacks the theory of Wallace that the duller colors of the female are acquired by natural selection. Thus there is found a difference in the colors of lizards where the female does not incubate and does not require the duller colors for the purpose of protection. In domestic fowl where danger from natural enemies is almost nothing the same difference in the color between the male and female continues. Thus the explanation is more fundamental than the one proposed by either Darwin or Wallace. Brooks bases his explanation upon a theory of heredity which supposes that the body gives off gemmules and that "the male reproductive cell has gradually acquired, as its special and distinctive function, a peculiar power to gather and store up these gemmules." The male cell, therefore, has acquired the power to transmit variation while the female cell keeps up the constancy of the species. "We thus look to the cells of the male body for the origin of most of the variations

through which the species has attained its present organization." Darwin said that the plumage and song of the male bird were transmitted by the selection on the part of the female of the gayest bird and the best singer. Brooks goes deeper and finds the cause for these secondary sexual characteristics in the power of the male cell to transmit the variations. He does not deny that the female may choose the best singer but affirms that the male must lead in variations from his very nature.

Geddes and Thompson carry forward still further the criticism of Wallace and Brooks. Wallace accounts, on the theory of natural selection, for the dull colors of the female and for the more brilliant colors and song of the male. Darwin on the other hand rivets his attention upon the gorgeous colors, the plumes, combs and wattles of the male, accounting for them by the theory of sexual selection but fails to tell us why the same process does not brighten up the coat of the female. The mere statement of the position must make it clear that there is some deeper cause than that discovered by either Darwin or Wallace, some internal factor much more powerful in its operation than any external cause. Geddes and Thompson finds this in the essential difference between the sexes. "The females incline to passivity, the male to activity." The female cochineal insect "spends much of its life like a mere quiescent gall on the cactus plant. The male, on the other hand, in his adult stage is agile, restless, and short lived." So with the other insects and other animals. The male is more active, while the female is passive.

For completeness of argument, two other facts may here be simply mentioned: (a) At the very threshold of sex difference we find that a little active cell or spore, unable to develop itself, unites in fatigue with a larger more quiescent individual. Here at the very first is the contrast between male and female. (b) The same antithesis is seen when we contrast the actively motile, minute, male element of most animals and many plants with the larger passively quiescent female cell or ovum.

To the above contrast of general habits two other items may be added on which accurate observation is still unfortunately very restricted. In some cases the body temperature, which is an index to the pitch of life, is distinctly lower in the females, and has been noted in cases so widely separate as the human species, insects, and plants. In many cases, furthermore, the longevity of the female is much greater. Such a fact as that women pay lower insurance premiums than do men, is often popularly accounted for by their greater immunity from accident, but the greater normal longevity on which the actuary calculates, has, as we begin to see, a far deeper and constitutional explanation.

The agility of males is not merely an adaptation to enable that sex to exercise its functions with relation to the other, but is a natural characteristic of the constitutional activity of maleness; and the small size of many male fishes is not an advantage at all, but simply again the result of the contrast between the more vegetative growth of the female and the costly activity of the male. So, brilliancy of color, exuberance of hair and feathers, activity of scent glands,

and even the development of weapons can not be satisfactorily explained by sexual selection alone, for this is merely a secondary factor. In origin and continued development they are outcrops of a male as opposed to a female constitution. To sum up the position in a paradox, all secondary sexual characters are at bottom primary and are expressions of the same general habit of body (or to use the medical term, diathesis), as that which results in the production of male elements in the one case, or female elements in the other.

This essential difference between the two sexes which expresses itself in differences of plumage and song is further emphasized by the facts, first, that many of the secondary sexual characters appear only at sexual maturity. Thus some of the male birds are dull colored when young like the female and acquire the brighter colors only on full development. Again, when the sex organs are removed by castration, the male ornaments or weapons of battle disappear. In cattle castration reduces the size of the horns, and after castration of the stag he never renews his antlers.

In the case of young cocks the effects of castration are very variable, sometimes increasing, sometimes decreasing the secondary sex characters. One result is clear, however, that the whole body is affected; the larynx is intermediate in size between that of cock and hen, the syrinx is weakly developed and the capons seldom crow or do so abnormally, the brain and heart are lighter in weight, fat accumulates in the subcutaneous and subserous connective tissues, and the skeleton shows many abnormalities.

The conclusion seems inevitable that neither Darwin nor Wallace reached the root of this matter. "The males are stronger, handsomer, or more emotional, simply because they are males; i. e., of more active physiological habit than their mates." This view does not wholly eliminate either natural or sexual selection. These may be limiting, and, in a sense, directive factors, but it is fundamentally the nature of sex which determines the gay color or the vigorous song.

To complete our review of this controversy which has been waged between ornithologists, we must record some of the more recent discussions of the Darwinian theory of sexual selection. Hudson says:

The result of such independent investigation will be a conviction that conscious sexual selection on the part of the female is not the cause of music and dancing performances in birds, nor of the brighter colors and ornaments that distinguish the male. It is true that the female of some species, both in the vertebrate and insect kingdoms, do exercise a preference; but in a vast majority of species the male takes the female he finds, or that he is able to win from other competitors; and if we go to the reptile class we find that in the ophidian order, which excels in variety and richness of color, there is no such thing as preferential mating; and if we go to the insect class, we find that in butterflies, which surpass all other creatures in their glorious beauty, the female gives herself up to the embrace of the first male that appears, or else is captured by the strongest male, just as she might be by a mantis or some other rapacious insect.

He accounts for the singing of birds by the abounding energy of birds.

We see that the inferior animals, when the conditions of life are favorable, are subject to periodical fits of gladness, affecting them powerfully and standing out in vivid contrast to their ordinary temper. And we know what this feeling is—this periodic intense elation which even civilized man occasionally experiences when in perfect health, more especially when young. There are moments when he is mad with joy, when he can not keep still, when his impulse is to sing and shout aloud and laugh at nothing, to run and leap and exert himself in some extravagant way. Among the heavier mammals the feeling is manifested in loud noises, bellowings and screamings, and in lumbering, uncouth motions—throwing up heels, pretended panics, and ponderous mock battles.

This is simply a repetition of Herbert Spencer's surplus-energy theory, which was based on the earlier theory of Schiller, who in his letters "On the *Æsthetic Education of Mankind*" wrote:

Nature has indeed granted, even to the creature devoid of reason more than the mere necessities of existence, and into the darkness of animal life has allowed a gleam of freedom to penetrate here and there. When hunger no longer torments the lion, and no beast of prey appears for him to fight, then his unemployed power finds another outlet. He fills the wilderness with his wild roars and his exuberant strength spends itself in aimless activity. In the mere joy of existence, insects swarm in the sunshine, and it is certainly not always the cry of want that we hear in the melodious rhythm of bird songs. There is evidently freedom in these manifestations, but not freedom from all necessity. The animal works when some want is the motive of his activity, and plays when a superabundance of energy forms his motive when overflowing life itself urges him to action.

It is too superficial a theory to satisfy the modern mind. We are compelled to ask the question, why does the male bird have more surplus energy than the female? This question throws us back to a consideration of the fundamental difference between the male and the female. There is only one answer to that question. The male sings more vigorously because he is a male, in other words because there is some fundamental difference between the sexes.

Karl Groos has contributed one very serious modification of the Darwinian theory which has not been given sufficient consideration by ornithologists, namely, that the song and antics of the male bird are not for the purpose of compelling her choice by the female but to overcome and break down her instinctive coyness. Nature has given the female coyness as a dam to nature's impulses to prevent the "too early and too frequent yielding of the sexual impulse." A high degree of excitement is necessary to break this down and hence the necessity for all the vigorous songs and antics of the male.

I am confident that this theory is destined to find wider acceptance in the future than it has in the past, indeed, that a large part of the song of birds before the nesting season is for the purpose of breaking down the reluctance of the female rather than compelling

her choice of a particular male. At Bakersfield, California, I spent an hour watching a male flicker sitting on a small limb a foot or more above his mate, while both birds went through motions that were interesting and at times almost ludicrous. The proud male would extend his head in a line with his body, then turn both body and neck first to one side and then the other, like a weather vane hung on a central shaft, at the same time jerking his head back and forth in a sort of kick-up motion, and pouring out all the time a quick succession of notes which might be represented by the words "pick-up, pick-up, pick-up," closing the whole performance by a right about face, when he would rest a minute and repeat the process. His less gaily colored mate was not so vigorous in her antics as her proud lord nor did she indulge in them so frequently but it was evident that he was making his impression and she could not refrain from expressing her feelings. I was certain that these birds had mated their lives "for better, for worse." Hence the love song could not have been for the purpose of mating, but to furnish the necessary excitation to make productive the season that was at hand for the reproduction of their race. There is no other explanation that can be given for birds already mated, unless it be that of the overflow of superabundant energy and this is too superficial an explanation for the deep laid plans of mother nature. Were this the only cause for the songs and antics of birds the mere overflow of nature might never terminate in anything or it might lead to unregulated abuse. But nature protects and regulates her ways by safety valves, of which the reluctance of the female is one, and this must be overcome before the reproductive process can become effective.

This view seems to be strengthened by the fact that the display of song and antics is used by polygamous birds and animals as well as by those which mate for the season or for life. The rooster with his harem about the barnyard is just as vigorous in his performances as the bird which is devoted to his single mate. The doe in her breeding time calls to the buck, who rushes to her side, then she, "half in coyness, half in mischief, takes to flight at his eager approach, makes toward an open space, and runs in a circle. The buck naturally follows, and the chase grows hot and exciting as a race of horses on a track. To the frequent high calls of the fleeing doe are added the deep, short cries of the panting buck; but suddenly the roguish doe disappears like a nymph into the thicket near at hand, and the baffled buck stands with head erect and ears thrown forward; then we see his head lowered as he catches the scent, and he, too, vanishes in the wood." But this deer is a polygamist and his antics can not be for the purpose of mating.

Watch the finch as he dances about his mate, fairly losing himself in a frenzy of ecstasy, flashing his wings in a wild delight and prancing about and chattering; the antics of the noisy street sparrow, the prancing and cooing of the pigeons, and there is only one evident conclusion. It is not for the purpose of mating but the more immediate purpose of hastening the female to fulfill her natural function. There are times when two or more males are involved in these antics, in which case there must be at least an unconscious choice on the part of the female, or a battle royal which will drive the competing males away, but in the vast majority of cases there is only one ardent male bird in the presence of the female, and he is often the bird with which she has already mated.

A weakness of the sexual selection theory that has not been given sufficient consideration is that the song of birds has been treated too exclusively in connection with the mating season. Men have riveted their attention on those rapturous bursts of song which precede and continue through the mating time, and have given too little attention to the fact that few birds are ever wholly voiceless, that most birds speak the sign or voice language, at least to some extent, all through the year.

Most of our best singers have two distinct song periods. One begins with the arrival of the advance guards of the migrating hosts and continues until the broods of young birds are hatched. When the young birds have left the nest and are able to care for themselves there is a cessation of the full, joyous songs, September being generally the silent month. Then many of the birds begin to sing the last of September or the first of October and continue until November. Bicknell has determined definitely the limits of these song periods for many of our birds. The house wren begins to sing its love song in April and continues to the last of July or the first of August. After a period of comparative silence it begins its autumn song which has none of the spontaneity of the spring song, but consists of a "low rambling warble," which continues to the middle of October. The black and white creeping warbler sings from April to the late June. Its second period begins from the ninth to the twenty-second of August and lasts only a few days. The first period of the oven bird stops by the end of June. The second period begins in August, at first haltingly, as though it had forgotten how to sing, but finally bursts into full song by October. The wood thrush sings from its arrival in late April or early May until the middle of August. It is not heard again until October and then only the call notes, never the full song.

Bicknell attributes this period of silence to the moult of the bird. In many cases the moulting periods of our song birds correspond more or less closely with periods of silence, voice being renewed

with the renewal of plumage. The general statement may therefore be made that birds are predisposed toward silence during the height of the moult. Though this fact may by many be regarded as one not requiring demonstration, it is by no means without exceptions. In the earlier and later stages of the moult the vigor of the birds in general seems little impaired. Not only do many species enter on their migrations while yet the moult is in progress or before the complete maturity of their renewal plumage, but birds may be found sitting upon their eggs with evident indications of activity in the growth of feathers. Still we must regard it as a general fact that singing and moulting are in some degree complementary.

Some birds have no second song period. The catbird sings from April through July, but is not heard in the autumn. The brown thrasher sings from April to the first week in July, but is silent in October. After August the scarlet tanager is not heard again in full song. Where this second period is lacking it is probably due to the excessive fatness of the bird. Thus the scarlet tanager undergoes its moult in August. The growth of the new feathers continues until October, when the bird becomes very fat. The wood thrush moults in August, but is not fat. By the last of September its plumage is nearly perfect and the bird is fat. Hence the song seems to be interrupted first by the moult and then by the adipose condition.

There are some cases where the birds' best song is outside of the mating season. It is a significant fact that the male birds arrive first in the migration and soon after their arrival begin their full song, though there are no females to hear. It may be said this is for the purpose of attracting the females on their arrival or that the male is practising his art, but this seems too superficial an explanation. There must be something within the bird himself which causes him to sing, though there is no ear to listen. Hudson calls attention to a small yellow field finch of La Plata which does its best singing in August. These birds gather in great flocks in the tops of trees and sing in concert, producing a "great volume of sound, as of a high wind when heard at a distance." Later this choir breaks up, love infects the individuals, and they scatter over fields and pasture lands. But during courtship the male has only a feeble, sketchy song.

There are birds which sing more or less the entire year. Hudson found several birds in Patagonia with good voices, 'one a mocking-bird, which were autumn and winter songsters.' Olive Thorne Miller tell of a gray-checked thrush in captivity which sang all winter.

All through the long winter this charming thrush, with his two neighbors, delighted the house with his peculiar and matchless music, and endeared himself by his gentle and lovely disposition. No harsh sound was ever heard from him; there was no intrusion upon the rights of others, and no vulgar quarrels disturbed his serene soul. (In *Nesting Time*, pp. 168-169.)

The voice of the crow is as vigorous in January as in June, and while I write these lines, in February, a blue jay is screaming from a tree in a neighbor's yard as though April had come. The chickadee sends out his cheery song the coldest day in winter with almost as much vim as he does in the nesting time. The metallic notes of the flicker ring over the hillside through the coldest months with a vigor becoming the hardy bird. Indeed, the man who goes forth into the New England hills in winter, especially if the sun happens to be shining brightly, must be impressed by the number of bird notes he will hear during the day. I went forth one day in January when the earth was encased in ice, over which was a thin layer of fluffy snow. A strong wind was blowing, whipping the bare branches of the trees. The thermometer was low and the air stinging, surely as unfavorable a day as one could find for birds. What was my delight to find a large flock of robins and another of goldfinches. The latter were as active and cheerful as though it had been a day in May. Defying the wind, they were in the tree tops, swinging on the tips of branches, sometimes hanging upside down, hunting eagerly for food. And from the tops of the trees their sweet, unobtrusive notes dropped down like bubbles of melody floating leisurely through the air. They were such a friendly company, no one showing jealousy because another had been more fortunate in finding food. Their concert of song was a free expression of their genial disposition, some birds uttering only single notes while others rolled out three or four syllables. I never heard a more hearty goldfinch chorus in the spring than they uttered on this cold January day, except it was not quite so loud as in April. The robins showed more effect of the cold weather sitting on a branch with their feathers fluffed out, as though to increase the size of their feather coat, but with all their discomfort they too indulged in song. Most of them gave the single robin note, but occasionally a more ambitious bird would roll out a longer phrase, one bird answering another that called from a distant tree. Then the entire flock would rise on wing, chirping as they flew, as though glad they were living and could not withhold an expression of their joy. From the top of the pines the crows cawed at each other, tipping their bodies as they called in a tilting motion, and protruding their necks and heads with each note.

The fact that is too seldom taken into consideration is that while the bird usually sings his most vigorous song and indulges in his most frantic efforts around the nesting season, he does use his

voice at other times during the year; that there are few birds that are entirely voiceless at any time. Sometimes he utters only a call note, again the note of alarm, caused by sudden fright, while again he sings apparently only for the pure joy of living. But throughout each month of the year either a sign or spoken language plays a part in the ceremony of his existence. His song is not merely a thing related to his sexual life. It has a relationship to his total existence. It is no more to be explained by the principle of sexual selection than is the existence of the human voice, even in its higher and finer modulation, by the same law. It is the means by which the bird expresses himself to the outer world. It is used according to the need of the hour or the season—the instrument by which the bird communicates his needs or feelings.

It is significant in this connection that so little has been said concerning the voice of the female. The question may reasonably be raised whether her voice is not much more important in nature's scheme than that of the male. He is a much more ardent, vigorous and accomplished singer. But after all that can be said about his song the fact remains that it is not so very important. It is a sort of grandstand performance. He is a sort of troubadour who comes forth to please those who hear, but it contributes nothing we can see toward the protection or rearing of the young. But who that has listened to the sweet, low notes of the mother to her young or the alarm notes or clucks which cause her helpless brood to run to hiding, can doubt that the voice of this female is very important in the struggle for existence. If the purpose of selection is the improvement of the race why might not some genius show that males select the mate with the best cluck or call for the protection of her brood? It would certainly be a theory far more in harmony with nature's plans. But, while no person would probably have the courage to prove such a theory, it can not be doubted that the female has a language and that it is far more important in the preservation of the race than the more modulated language of the male.

All of these facts must be taken into consideration before we can adequately account for the song of birds. The sexual selection theory is based too exclusively upon one period in the bird's life. The bird has more than one season of song and there is no month of the year when his voice does not play some part in his life. The female has a language as well as the male. It must be evident that any explanation which will be adequate to account for bird language must cover every season and must be found in the inner life of the bird rather than in outward circumstances or choices.

Again there are certain types of sign language which are much more universal among birds than has generally been assumed. Much emphasis has been placed upon the displays and love dances of

pheasants and birds of paradise which, it has been assumed, was the cause of the beautiful plumage of these birds. The female choosing the best performer or the most highly colored male has resulted through slight modification, generation after generation, in these elaborate decorations. But we have, since Darwin, discovered that the love dance or display is in some measure used by many birds, often birds of dull color, like the English sparrow, and they are still, in spite of the love dance, dressed in gray or sober plumage. Howard, in his remarkable *History of the British Warblers*, has shown "that these birds of sober hues perform during moments of sexual exaltation, antics which in every way reflect the display supposed to be peculiar to birds of brilliant plumage." Savi's warbler also indulges in these antics even when feeding his young. Furthermore, these dances are not confined to the period of courtship.

From whatever point of view we approach this subject the evidence is so strong that we are compelled to look for our explanation in the internal life of the bird rather than in any external, exciting cause. Most of the theories thus far set forth have in them an element of truth. If the purpose of song is excitation of the female to break down her coyness, this very act may compel her to exercise an unconscious choice and thus sexual selection may exert a limiting and directive force in the life of the bird. Even Hudson's theory that the bird sings out of the abundance of its very being, joy and life, is not to be ignored. But the question forces itself upon us, why does the bird sing and dance to overcome the female coyness and what gives the male more vitality than the female? The answers to these questions force us back into the inner life of the bird to seek our answer in the essential difference between the sexes.

So far as song, as well as other displays, in the mating season are concerned they are due to the ripening of the sexual glands, from which, as Pycraft has shown, hormones are set free, and, pervading the body, stimulate the nervous system, and at the same time the secondary sexual characters—the antlers of the stag, the mammary glands of the female, the "breeding plumage" of the bird. When they are obviously secondary sexual characters, as in the case of dull-colored birds, the result is the same, a state of physical exaltation expressed in "display." Males or females wherein these "hormones" are but feebly developed, display and respond indifferently, and so cease to please the opposite sex. As Mr. Howard has pointed out, in the case of the warblers, no amount of display on the part of the male will avail until the female has attained a like pitch of preparedness for the work of procreation. The courtship of the ruffs and reeves, already referred to, affords another illustration. Here it will be remembered the males for weeks spend laborious days in endeavoring to gain some responsive sign from their prospective but phlegmatic mates, yet without receiving the slightest sign of encouragement or recognition. As soon, however, as the female has become "sexually ripe," as soon as the hormones secreted by her generative glands have done their work, she herself indulges in a species of nuptial dance, waltzing round her lord, and setting down

before him with her tail directed toward his head. Thus the sexual activity displayed by the male comes to mean simply that he is more ardent at this time than his mate. The advantage of this is obvious for thereby the more vigorous males, by proclaiming their desire to pair, defeat their less vigorous rivals, who might otherwise be chosen. The earlier they can take the field, the more persistent their advances, the greater their chance of ultimate success, and this because they slowly instill a preference which can not be overcome by later and less virile comers.

This fact makes it clear why many of the sober-tinted birds are as ardent in their love dances and displays as some of the more brilliantly colored birds like the peacock and the pheasant. It may also explain why some of the more brilliantly colored birds sing as vigorously as the duller-tinted species. Their nervous system is in a condition of intense stimulation through the action of secretions thrown off by the sex glands. But the important fact is that it completely modifies the theory of sexual selection, so modifying it that there is little of the significance attributed to it by Darwin and his followers remaining. The antics, display, and songs of birds are germinal variations which have survived and are not the result of conscious or unconscious choice on the part of the female. This is "borne out by the fact that birds of the most sober hues affect displays of a character precisely similar in kind to those of birds in which this display appears to be made for the sole purpose of exhibiting to the best advantage some specially modified or beautiful colored feathers."

This view which seeks the cause of song in the internal life of the bird rather than in external causes also gives a more satisfactory view of the total language of the bird, the call and alarm notes, the gentle notes of the mother bird over her young, and the songs that are uttered outside of the mating season. The sexual selection theory has fallen down, in my judgment, from the fact that it has confined itself too exclusively with one short period in the language of the bird. It has failed almost exclusively to recognize that birds have a language which extends throughout the entire year, either sign or tone language, and that there must be something in the feathered creature which will account for this less vigorous expression of life and needs which occurs outside of the mating season. It is here that the theory of germinal variations comes to our assistance. Voice having originated in the hisses and groans of the reptile, it was inevitable that there should be a difference both of tone and vigor between the male and female birds, due to the essential difference of sex and any variations in voice which might arise would be preserved in the male germ which assures the variation in the species while the germ of the female guarantees the constancy of the species.

MARINE CAMOUFLEURS AND THEIR CAMOUFLAGE: THE PRESENT AND PROSPECTIVE SIGNIFICANCE OF FACTS REGARDING THE COLORATION OF TROPICAL FISHES.

By W. H. LONGLEY.

[With five plates.]

Shortly before his death the late Col. Roosevelt wrote:¹ "In its groundwork essentials the matter of animal coloration is one of kindergarten simplicity." But, as a minor result of the World War, knowledge is widely disseminated which shakes confidence in the finality of this conclusion.

For years our harbors have been choked with ships in bizarre war paint, designed to deceive the enemy regarding their apparent size, speed, and direction of motion. During the same period, tanks, great guns, and other implements of war upon the battlefields of the world have been painted on much the same system, with the general result, paradoxical as it seems, that their visibility has been diminished. But if daubing a gun with irregular patches of vivid and contrastive color increases the difficulty with which it is discovered by aerial observers, this fact, wholly opposed as it is to preconceived opinion, may lead one to suspect, with regard to animal coloration, that underlying principles may not always be obvious; and to infer too, that Col. Roosevelt's plummet may not have reached bottom in depths he believed he had sounded.

The differences in color between closely related species of animals are often more striking than any other marks which serve to distinguish them one from another. But, upon the basis of the Darwinian hypothesis, the more noteworthy the difference between two forms, the more important, upon the average, should have been the rôle of natural selection in bringing it into being. The greater the difference, the greater too should be the ease with which the service rendered by divergent characters of related species should be demonstrated. These facts sufficiently explain the sustained interest of Darwinians in animal coloration; here, in a sense, they have elected to stand and to demonstrate the existence of that general fit-

ness for survival, that adaptation to environment, which should characterize animals, if their evolution has proceeded as they suppose.

Almost by common consent such animals as the hare, woodcock, tree frog, flounder, and a host of others, both terrestrial and marine, are considered obliteratively colored. Indeed, the extent to which the colors, and even the patterns of some of these animals, repeat those of their surroundings, and the difficulty with which they are discovered when at rest, leave little room for dispute regarding the significance of their coloration. But it is otherwise with animals which display patterns of massed colors in sharp contrast with one another and with no obvious tendency to repeat those of the environment in which their possessor may be observed, at least at times.

Even the general reader who only occasionally seeks diversion in biological literature will recognize in these patterns a familiar bone of contention. To some persons they have seemed to owe their brilliance and conspicuousness to sexual selection. In the opinion of others they warn potential enemies of unpalatability upon the part of their prospective prey, and so preserve the latter from unwelcome and dangerous attack. Still others see in such patterns marks developed through ministering to recognition at a distance between members of the same species. It has also been held that such types of coloration contribute nothing to their possessors' welfare and are to be regarded merely as an indication of their immunity from attack on account of their agility or other advantage they enjoy. Finally, and, as it seemed, most preposterously, until recent events placed the matter in a new light, it has been suggested that they are as truly obliterative in function as others. These patterns of the second sort differ, however, from those of the first in having to discharge their function under different conditions, to which fact they owe their peculiarities.

For the last suggestion zoology is indebted to Mr. Abbott H. Thayer,¹ whose contribution to an understanding of animal coloration has been most substantial. America, however, has been rather backward in expressing appreciation of Mr. Thayer's discoveries. It may therefore be of interest to present in brief certain findings of an entirely independent order which consistently support the general principles he enunciates, whose truth and significance are not yet thoroughly comprehended.

The findings in question² are almost exclusively derived from field studies of fishes and crustacea, which involved the use of equipment not commonly employed in such work. The whole may be seen in action in plate 1, figure 1, which shows the launch *Darwin*, of the

¹ See Abbott H. Thayer, *Concealing Coloration in the Animal Kingdom*. Macmillan, New York, 1909.

² For a detailed statement, see the *Journal of Experimental Zoology*, vol. 23, 1917, and recent issues of the *Year Book of the Carnegie Institution of Washington*.

department of marine biology of the Carnegie Institution of Washington, her complement of men, and the diving hood and camera which made the chief investigation possible and permitted a pictorial record of some of the observed facts to be secured.

As will appear from the picture, the hood affords one no protection from the water. It is simply an inverted, weighted, metal cylinder, cut to fit the shoulders, and connected with a compression pump by a hose through which its contained air may be renewed. In practice its weight is slightly more than sufficient to overcome the natural buoyancy of the operator. It is simple, safe, and convenient to handle; yet it permits one to work upon the bottom in warm tropical water for hours at a depth of 10 to 15 feet, with only one's head in the bubble of air it holds.

Provided with such a hood, and enjoying the comparative freedom of movement assured by the use of 100 feet of hose, one has an unusual opportunity to observe the behavior of representative marine animals under natural conditions. Most of the creatures show little fear of the strange thing they see, until it is fairly upon them. Schooling nocturnal fishes continue to rest idly about their gathering places. Diurnal species, upon the other hand, come and go, intent upon important business. Carnivorous forms, indeed, far from taking flight, may even gather around one to search for possible food to be discovered about overturned stones, while herbivorous types pass and repass, it may be in droves, cropping the more or less dense turf of algae which covers the reefs.

It is a strange world in which the diver finds himself; it is so small and still; so surrounded by mystery; so surprisingly unlike that which one imagines it to be, observing it from the surface. Even when the light is brightest and the water most free from sediment, one never sees objects at a greater distance than a few yards;¹ and if a heavy surf is pounding a short distance seaward, so much débris may be borne inshore on the rising tide that one may be shut in almost as completely as in a blinding snowstorm, and have no means of finding one's way back to the boat other than following the hose. No sound reaches one save that of the air rushing into the hood at each stroke of the pump above. Graceful gorgonians, purple, brown, yellow, or olive, may sway gently as the lazy swell rolls overhead; or as one clambers about the face of some submerged escarpment, one may see, from below, sheets of foam spreading where trampling rollers raised by an incessant trade wind have broken. Yet all transpires in perfect silence.

A feature which contributes in high degree to the strangeness and unreality of one's surroundings is the fact that while in the hori-

¹ In one instance under very favorable conditions the visibility was found to be 15 paces

zontal plane one's world suffers diminution, all vertical distances prove to be much greater than they appear from the surface of the water. Apparent smooth bottoms are rough; rough ones are seamed by crevasses ragged with overhanging ledges, or are pitted with holes scoured by the waves and communicating with one another at times beneath natural bridges. Yet, however rough the bottom, one carries one's load of metal with ease, since its effective weight is so greatly reduced in water. One even scales near-vertical precipices without difficulty, for the same reason. But, light as one feels, real speed is out of the question, and the horizon is very near. It is therefore well, perhaps, that upon every hand interesting things claim one's attention, or active imagination might dwell too much for comfort upon terra incognita which the hood's one narrow window permits even to touch one from the rear.

The animal life on a rich tropical reef will engross the powers of observation of a naturalist for an indefinite period, even if he is able to study it only from a boat through a water glass; but its appeal to his interest is intensified when he is able actually to stand upon bottom, beneath water, in the very midst of the creatures observed. This is due to several factors. Limited as one's range of vision is by the opacity of the water and its suspended sediment, one still sees more and more clearly upon the whole, when submerged than under any other condition. No reflection from the water's surface, and no inability to manipulate one's water glass satisfactorily, robs one of the last act of innumerable dramas staged by the reef population. Again, many of the most interesting creatures to be seen, or features in their behavior, can not be made out clearly at distances which must intervene between them and an observer at the surface. Finally, fishes in particular, among marine animals, are not adjusted alone to a world beneath them. One needs, therefore, in many instances to see them from below, against what lies above, in order to grasp the full meaning of their coloration.

Some of the glimpses a diver catches of the normal lives of the animals by which he is surrounded are highly instructive. He may find, for example, even on what seems the loose and shifting sand of a submarine Sahara representative species whose habits and structure accord with their surroundings. There are flounders there marked with the color and pattern of the bottom beneath them, which while he watches will bed themselves and be lost from sight in an instant, except as their prominent eyes rise beyond the general surface of the body, and above the drifting sand, keep watchful outlook upon local happenings. Pale, hatchet-faced razor fishes of one genus or another may also be in evidence, sidling away leisurely as he advances, and ready ever to demonstrate the ease with which their peculiar form enables them to cleave the sand, dart from sight, and lose them-

selves in the barren waste. A bit of food will often bring crabs out of hiding, too, to scuttle over the bottom, whose characteristic features are faithfully repeated in their own markings. But if one may judge from their behavior in tanks, the day is not their preferred time for roving, and after a little they almost invariably give what in any animal not covered by a firm exoskeleton would be a shrug or two, and scraping and scratching with their hind legs go down backwards out of sight.

Thus one finds peculiar structures discharging odd functions, and so interpreting themselves. Proof is obtained, too, that reactions are normal which one sees from time to time among one's captive animals. But often one observes incidents which remain incomprehensible, as when two yellow grunts (*Haemulon sciurus*) approach one another slowly, snout to snout, open their mouths to the limit of their gape, and gaze, as it seems, for several seconds, as if in rapt attention, each at the patch of bright red in the buccal cavity of the other. Nor is it clearer why from tiny holes in dead pieces of coral a small unidentified species of fish with an enormous dorsal fin should protrude half its body and rapidly and repeatedly elevate and depress its great banner, while another seems to respond in kind to the signal.

One of the most striking things to be observed at favorable places is the abundance of fishes. Not only are hundreds of individuals to be seen without changing one's station, but as many as 50 species have been noted at one spot within an hour. Since all are so near that almost without exception detailed comparison of appearance and behavior is possible even to the unaided eye, it is obvious that comparable advantages may be enjoyed rarely, if ever, in respect to other groups of animals.

The places at which species so abound are ideal points at which to learn to distinguish the different forms, and to become familiar with their appearance in life, which is commonly very different from that of dead specimens, even when freshly taken. For advanced students of the behavior of the species concerned such places possess additional advantages, for it is sometimes possible to see there side by side types not occurring elsewhere together, and to verify tentative conclusions regarding their specific difference in habits which may rest upon observations made upon them separately. As points, however, at which study of behavior should be begun, and particularly as stations at which by study one might hope to determine the significance of the animals' colors and patterns, few places could be less propitious. They are average, or typical, environments for a comparatively small number of the species present; and it is in its typical environment that one of these creatures should be seen in order that the significance of its

coloration may be apprehended; for it is to that environment that it is adapted.

It is a simple proposition, and should be self-evident, that, although two species may often be seen doing the same things together, neither their distribution nor the range of their activities is therefore of necessity identical. Nevertheless, writers overlook this fact, and reason unsoundly that because two or more species occur together, pursuing their occupations "cheek by jowl," and yet differ in pigmentation, both can not be obliteratively colored.

Painters and plumbers, capitalists and coal heavers, may at times be seen together similarly engaged, yet their differences in dress and demeanor are not without practical relation to their respective callings. No one forgets that they are not always rubbing shoulders reading the same newspaper bulletins, or paying the same income taxes. Similarly, although the colors displayed by mixed swarms of fishes upon the reef are varied, although some are matched by nothing one sees in their vicinity and the patterns in which they appear may be highly contrastive, each particular combination may serve, and serve in essentially the same way, under the conditions in which it is most commonly to be seen. The truth will appear, however, only when the different species have been observed under many conditions, and the range and activities of each have been defined; until which time no one's suggestion of the revealing or concealing effect of their colors and patterns may claim to rank higher than an interesting working hypothesis.

In determining when and where a given species is to be found, and how it spends its time, which are the fundamental facts concerning it in the present connection, no single method is more valuable than the analysis of stomach contents of individuals taken from as many and varied localities as possible, and at all times of day and night when they may be secured.

Application of this principle shows that there is, on the whole, a sharp distinction between diurnal and nocturnal species, since comparatively few seek and capture food indifferently at all hours. To which group a form belongs is usually clearly indicated by the amount and the stage in digestion attained by the food in the fishes' alimentary tract morning and evening. In some species every individual of hundreds examined will be full at daylight and fasting at sunset. Species of which this is true commonly school at definite points during the day.

The fishes in figure 2, plate 1, are in characteristic grouping in typical surroundings. Such small knots, and larger aggregations of nocturnal feeders, are semipermanent in composition; for individuals which may be distinguished by some peculiarity, such as size, wounds, scars, or malformations, may be seen day after day at the same place.

Knowledge of this fact, and of the fact that at night these species feed upon food of definite sort, whose range is known, permits one at last to speak with some confidence regarding their distribution at different hours.

Important, however, as is the information gained through determination of the feeding habits of fishes, or of other animals, through analysis of their stomach contents, the vividness of one's mental picture of their daily round of activity is increased immeasurably by direct observation of their behavior. Nothing could be clearer than the import of masses of statistics showing that some fishes feed by night and others by day. Yet his conception of the fact is pale and colorless who has not seen the nocturnal species coming in at daylight singly, or in twos or threes, until their accustomed schooling places swarm with them; or who has not noted, at dusk, forms which have been active all day disappearing, in what way it is almost impossible to discover, while others from the inner, dimly lighted, secluded fastnesses of the reef, come out of obscurity somewhat before, but with as little confusion, and with almost as definite an order of appearance, as the stars in the twilight.

At many points the method of direct observation yields results, however, which could never be inferred, even from complete knowledge of the food of fishes and the conditions under which it is taken. This is the case with all the minor diurnal activities of nocturnal species; and is quite as true of the common changes of color, shade, and pattern, which species of the most diverse sort effect under a great variety of conditions. With respect to all such matters it is indispensable, and the results to be obtained by pursuing it are crucial in determining the significance of the coloration of fishes.

To secure a comprehensive pictorial record of specific differences in behavior it is practically necessary to use a camera inclosed in a water-tight container more or less after the model of that shown in figure 1, plate 2. The submarine photographs illustrating this article were obtained with a 4 by 5 autograflex camera, protected as appears in the picture. The camera "looks" through a circular window in the left end of the box. What is in focus in the field of the lens appears upside down in the mirror mounted in the upper end of the focussing hood. The act of focussing, the tripping of the shutter, and other operations necessary in making either instantaneous or time exposures are made by various screws and plungers, some of which are not visible in the figure. It is necessary to send the box to the surface for the purpose of changing the plate after each exposure.

The difficulty with which pictures may be secured varies with circumstances. When the light is good an exposure of a tenth of a second is sufficient; that is, a snapshot may be taken; and if the subject is reasonably quiet and the water calm, it is not particularly

difficult to secure the result desired. But one's trials mount very rapidly with failing illumination, shyness of the subjects, their activity, and, above all, with the roughness of the water. The camera box is large and somewhat awkward to handle. It requires both hands and knees to steady and manipulate it. In the meantime while one is using it the heavy hood, left to its own devices, except insofar as it may be steadied against the camera by pressure of the forehead, rides upright or otherwise according to conditions. The long rolling swell pushes one now a step or two forward, now back too far to accomplish anything, and meanwhile the image in the mirror, never overbright, goes into complete eclipse, as one's breath condenses upon the window of the hood. Then whatever advantage of position may have been gained for the moment has to be abandoned; the glass must be flooded with water and the attempt renewed from the beginning.

The camera readily records such differences in regard to their habits, as appear in the case of the fishes shown in plates 1 and 2. The former, as has been said, are nocturnal; the latter, diurnal reef rangers. The one class, as one might infer from the picture, is marked in general by its comparative inertia when undisturbed; the other is equally characterized by its restless activity.

Each of these primary groups includes a great variety of species, and is capable of subdivision upon the basis of differences in distribution and behavior. Some fishes sedulously avoid the light, and in proportion to their numbers are rarely seen. Others swarm about the coral beds or stacks, and are not found at all upon the open reef. Some are found chiefly, or solely, on sandy bottoms; others among particular sorts of marine vegetation. Some haunt the bottom; some, the surface; some, again, the intermediate depths; while others may swim at any level. Now follows a fact of great significance: When the fishes are grouped naturally upon the basis of their microgeographical distribution, so to speak, it appears that the range of variation in color is much less upon the average within each of the subordinate groups than it would be in a group of the same size selected at random from the local fish fauna as a whole. In addition the colors dominant in the different groups are correlated in general in a definite way with those of the preferred haunts of the group, and tend to repeat them. This seems to indicate almost as clearly as anything can that the colors of the fishes in question are upon the whole what they should be in order to make them inconspicuous in their normal surroundings.

This is quite at variance with the conclusion naturally drawn from the appearance together of many species of different colors in one circumscribed region. But, with few exceptions, readily recognized as such, the places where species congregate most freely are foci where many simpler environments meet, or even overlies one another.

Each individual which one sees commonly at such a place, if it is not frankly a stray specimen, is adjusted to some one or more of the various factors which make up its complex environment of the moment. To others it is more or less unadapted, and its lack of adaptation in so far as color is concerned may make it appear conspicuous. It is impossible to consider its conspicuousness functional, however, something which nature has elaborated through selection on account of its revealing quality. It is not even possible to look upon it as something of no significance, upon which nature has placed no check. Such as it is, it is a sort of residual, and possibly irreducible, conspicuousness; for species, as gaudy as any, possess marked power of adaptive color change.

That many fishes, those from tropical waters in particular, may vary greatly in color from moment to moment, has long been known. A few moments' observation of the fishes in the tanks of the New York aquarium, for example, even when the observer sees the creatures for the first time and lacks more than the average intelligent person's interest in them, will make clear their power of color change. Under what conditions this power is exercised in nature, and whether the color changes of unconfined fishes in their native surroundings conform to law, has, however, until recently never been determined on any comprehensive scale.

This deficiency in biological knowledge is probably due to the fact that for the most part the visits of biologists to tropical reefs, where the changeable species are best to be observed, have chiefly been of short duration, and, in so far as they have been concerned at all with fishes, have been devoted to collection, rather than to the study in life of local species. Under such circumstances the students, or collectors, as the case may be, have gone chiefly to those places where fishes most abound, to places, in other words, where the underlying system their color changes follow is to be perceived with greatest difficulty.

What it is that determines that color shall change in changeable species, and how strictly utilitarian the changes are in their general effect, appears most clearly when the creatures are observed at some point where large areas of rather uniform character meet others from which they differ sharply in color. Such, for example, are the boundary lines between bare bottoms covered with clean white sand and those covered by a dense mat of brown seaweeds or green marine plants of one sort or another. If at such critical points one watches passing fishes that are equally at home on either side of the line they may be seen making appropriate changes as they pass from one to the other. One has to wait largely upon the haphazard movements of herbivorous species in order to secure demonstration of the law in accordance with which their color changes occur; but with a broken

sea urchin, or any other such titbit, carnivorous fishes of small or medium size may be drawn from point to point, and their color changes evoked at will. In the face of these and other facts even the most skeptical must accept the complex mechanism of color change in fishes, as a device whose chief function is to enable the species that possess it to display obliterative hues in typical surroundings within their specific ranges, in which they are and have been through ages accustomed to move in the course of their normal activities.

It is difficult and perhaps impossible to translate the details of a fish's coloration into terms of service rendered. It is conceivable and highly probable that many of its lesser peculiarities are without biological significance. It is clear, however, that in the gross it serves to blend its possessor with its environment and tends to obliterate it, one should suppose, in the eyes of potential enemies or prospective prey. In view of the incidence of the power of color change within the group, and of the correlation of the color of fishes with their habits and distribution, there is no reason to suppose that revealing and concealing types of coloration may be distinguished among them. Broadly conceived, all their coloration, so far as the evidence goes, is obliterative in effect.

This fact is rich in suggestion. All the Darwinian hypotheses of animal coloration have really grown out of effort to explain how animals' colors and patterns serve them in the struggle for existence. For if such characteristic features as the markings of animals are without utility, the hypothesis of organic evolution by natural selection possesses at best no general application. This is indeed an opinion held by many biologists. But let Darwinians, in a day when the lives of men by thousands have been staked upon the truth of a contrary conception, forswear allegiance to the fetish of warning coloration. Let them spend in the field whatever time is necessary in order to determine in what relation the colors of birds and insects stand to those of their surroundings, and whether they are correlated with their significant habits and distribution. Then we may gain at last a comprehensive view of animal coloration consistent with fact. In that case, if we may hazard a prophecy, the hypothesis of natural selection should regain in time much of its departed glory; for there is reason to believe that the doctrine of utility will be generally sustained in regard to the coloration of the higher animals.

The prospective significance of known facts regarding the coloration of reef fishes is not readily to be stated. It is largely bound up with the subject of changeable patterns; for not only do fishes change their color and shade, but some have two or more alternative systems of markings in which their colors may appear.

Some patterns which are not changeable seem to be correlated with definite habits. In the case of others which are changeable there is conclusive evidence that they are displayed under specific conditions. One may almost dare state it as a law, that when any species has alternative patterns of longitudinal stripes (or self-color) and transverse bands, the former is shown when the fish that displays it is in motion, while the latter tends strongly to appear whenever it comes to rest.¹

To be able to say so much is decidedly encouraging. The color patterns of fishes are more than variegated pigment patches compounded at random; they possess biological significance. Whoever reads the riddle of their organization, and comprehends the order of their changes, will discover the essential principles of a natural system of camouflage. In the changeable colors, and even more in the changeable patterns of fishes, he should find, too, a delicate physiological indicator, through changes in which variation in psychic states should be observed to advantage.

¹Since this was written it has been observed that like many fishes the squid (*Sepia* sp.) when at rest in the water is transversely banded, but replaces these bands by longitudinal stripes when it begins to move.

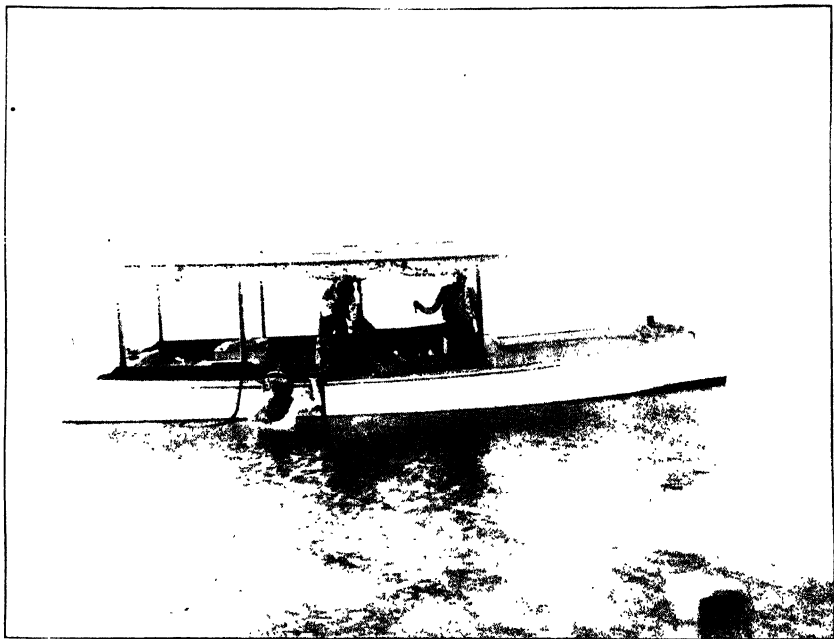


FIG. 1.—LAUNCH DARWIN. DIVER ABOUT TO DESCEND WITH CAMERA.

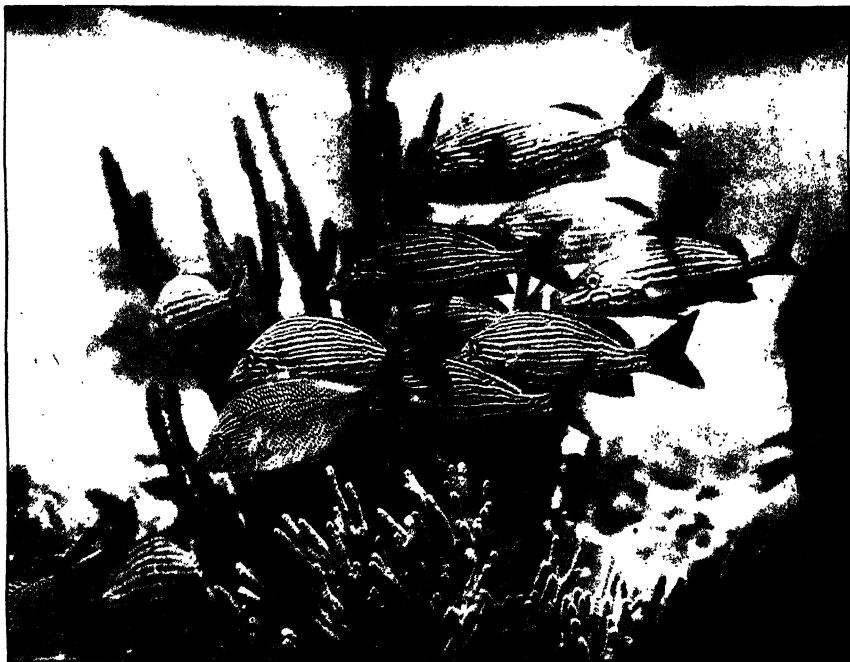


FIG. 2.—YELLOW GRUNTS (*HAEMULON SCIURUS*) AND A COMMON GRUNT (*H. PLUMIERI*) IDLING THE DAY AWAY AMONG GORGONIANS.

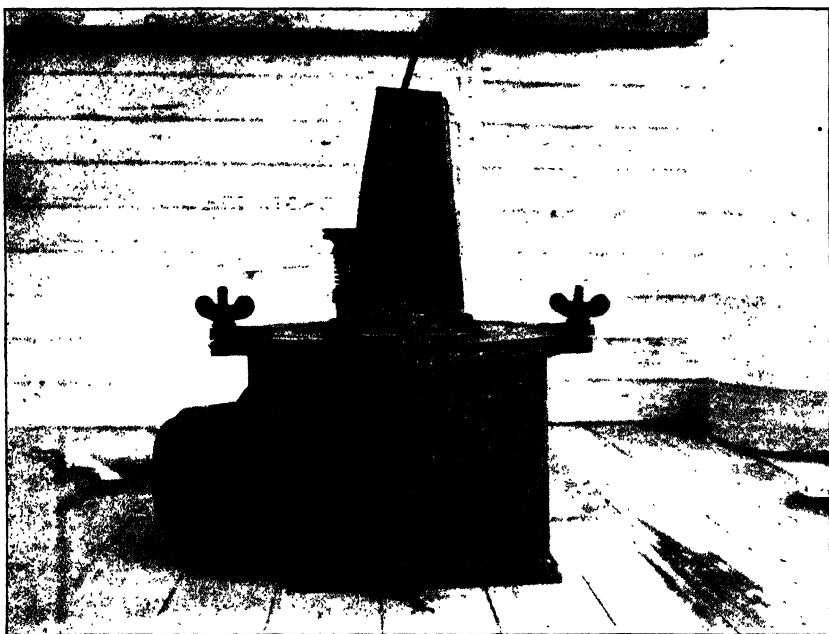


FIG. 1.—WATER-TIGHT CAMERA HOLDER USED IN SUBMARINE PHOTOGRAPHY.



FIG. 2.—RED GOATFISH (*UPENEUS MACULATUS*), YELLOWTAIL (*Ocyurus chrysurus*), AND *IRIDIO BIVITTATUS*, DIURNAL FISHES, SEARCHING FOR FOOD TOGETHER.



FIG. 1.—YELLOW GOATFISH (*UPENEUS MARTINICUS*) SCHOOLING WITH *HAEMULON SCIURUS* ABOUT MASSIVE CORALS.



FIG. 2.—RED PARROTFISH (*SPARISOMA ABILDGAARDII*) IN ONE OF ITS VARIED COLOR PHASES AMID GORGONIANS.



FIG. 1.—BUTTERFLY FISH (*CHAETODON OCELLATUS*).

These dainty little fishes are commonly seen in pairs as shown.



FIG. 2.—FIGHTING GRUNTS (*HAEMULON PLUMIERI*).

The one at the left has taken its station over the Gorgonian tuft and resents intrusion.



SCHOOLING PORKFISHES (*ANISOTREMUS VIRGINICUS*), MASSIVE CORAL, AND LONG-SPINED, NEEDLE-POINTED SEA URCHINS.

FOOT-PLOW AGRICULTURE IN PERU.

By O. F. COOK.

[With four plates.]

Three principal types or systems are to be recognized in the study of the highly specialized agriculture of the ancient Peruvians. In the lower valleys, at altitudes less than 5,000 feet, farming probably was limited to the more primitive milpa system, the same that is still followed generally in tropical America in regions of low elevation. Under the milpa system a new "farm" is made each year by cutting and burning the trees or bushes, which clears the land for planting and renders cultivation unnecessary. In some countries it is customary to raise a second crop, which may receive a little weeding or hoeing, but the land is not kept in cultivation continuously. There must be a new growth of trees or bushes before the same place can be cleared again by burning.

Above the milpa belt, in the intermediate or temperate valleys of the eastern Andes, at altitudes between 5,000 and 11,000 feet, agriculture was of the terrace system, which the ancient Peruvians carried to a higher development than any other people. The megalithic retaining walls, built of huge rocks, unsquared, but fitted together with precision, testify to a high degree of industry, organization, and skill, and must be reckoned among the chief wonders of the ancient world. Hundreds of square miles of land were reclaimed by straightening rivers, walling, filling, leveling, and covering with a deep layer of fine soil. All of these artificial lands had also to be irrigated, often by carrying the water channels for many miles through craggy mountains or along precipitous slopes. After being cropped with maize continuously for centuries the terrace farms are still fertile, and have enabled millions of people to live in a region that in its natural condition could have been of no use for agriculture purposes.¹

In still higher valleys, at altitudes of from 11,000 to 14,000 feet, the climate is colder, moisture is more abundant, and the slopes are more gentle. There is less need of terracing or of irrigation, but the alpine grasses and other small plants form a dense, fibrous turf, a condition like that of northern countries where the plow is the basic

¹ See Staircase Farms of the Ancients, National Geographic Magazine for May, 1916.

implement of agriculture. Though the early accounts show that llamas were employed extensively, as beasts of burden the ancient Peruvians appear to have devised no means of using these animals for draft purposes or to assist in the cultivation of the soil. The farming of the mountain grasslands was done by human labor, facilitated by a peculiar implement for breaking the sod.

The Peruvian foot plow, in the Quichua language called *taclla* or *chaquitaclla*, consists of a rather stout wooden handle, between 5 and 6 feet long, shod in modern times with an iron point about 3 inches wide and two or three times as long. On the left side just above the iron point, is a foot rest, bound to the handle by leathern thongs. A few inches farther up is another rest attached in the same way, projecting forward. The second rest is for the left hand, which thus assists the foot in applying the weight of the body to the pushing of the implement into the soil. Middendorff's idea of the *taclla* being worked with both feet may have been suggested by the presence of the two projecting pieces, but one foot would be needed on the ground.

Other names for native Peruvian plows are *arma* and *yapuna*, recorded by Holguin and Middendorff, respectively. The verb to plow is *yapuy* or *yapuni*, and *yapuk* is a plowman. In the Aymara language, spoken in the high tablelands around Lake Titicaca, *yapa* is a field or farm, corresponding to *chacra* in Quichua. Among the Quichua words that may be related to *taclla* are *tacllamaqui*, the palm of the hand, and *tacllani*, meaning to slap or to knead, which might refer to plowing. Another verb, *takiyani*, meaning to fix or make firm, might allude to the lashing on of the rests for the foot and the hand. Holguin gives *suruna* as the name of the foot rest of the *taclla*. The word *chaquilpa* is defined as a part of a *chaquitaclla*, and *huisu* as a stick that is lashed to a plow.

The plowmen do not work alone, but two together, so that their *tacllas* enter the soil only a few inches apart, under the same piece of sod, which is then pried up. A boy or woman kneels in front of each team of plowmen to turn the sods as fast as they are loosened. There is also a special word, *racra*, defined by Holguin as the boy who turns the sod in plowing. Effort is required in driving the *taclla* into the ground, as well as in prying up the sod. In the rarified atmosphere of the high altitudes plowing with the *taclla* is very strenuous exercise. The men are soon out of breath, and the work has to be done in short "heats." While the operation might be compared to spading, there are three notable differences—the way of handling the tool, the tearing of the sod, instead of cutting it, and the turning of the sod by hand instead of lifting and reversing it with the spade. The *taclla* is like a narrow spade, or spud, but

this tool has a sharp cutting edge, and is used to extirpate thistles or other deep-rooted weeds, not for breaking the sod.

The work that was being done on the slopes along the pass of La Raya in the middle of April, 1915, corresponds to fall plowing in northern latitudes. Only narrow strips of sod were being turned at this time, marking the rows where the potatoes were to be planted, but all of the ground is broken later and the tough sod disintegrates during the long growing season into a loose black soil. The cultivation of potatoes is carried to an altitude of more than 14,000 feet on the southern slopes of the valley in the district between Santa Rosa and Araranca.

Agriculture in the high altitudes becomes strictly subordinate to pastoral activities, the feeding of flocks of llamas, alpacas, and sheep on the grassy lands above the range of cultivation. The hardest varieties of potatoes are too bitter to be eaten in the fresh state, but are dried as a reserve stock of food, after freezing, thawing, and treading out the juice. The natives are familiar with the names, habits, and distinctive qualities of many varieties of potatoes, including several types that are very different from any known in the United States. The flavors, colors, and textures of the different kinds of potatoes are as keenly appreciated among the high-altitude people as the varieties of apples or peaches are with us. In the pass of Panticalla a hospitable Indian farmer favored us with boiled potatoes to eat out of hand, and insisted that we put the remainder of our "treat" in our pockets. The firm textures and distinct flavors of the Peruvian varieties may be due in part to their being less affected by cooking, since water boils at lower temperatures in the high altitudes. Potatoes are not baked or roasted, fuel being too scarce.

At the upper limit of agriculture in the pass of La Raya the only crop associated with the potato is a small species of chenopodium, called *cañihua* (canyéwa). In the year after potatoes a crop of *cañihua* is grown on the same land, with no additional preparation. The *cañihua* is not the same as the better known *quinoa*, which is grown at somewhat lower elevations, but is a smaller plant with smaller seeds, not bitter like most varieties of *quinoa*. The *cañihua* is sown broadcast, requires no cultivation, and is gathered by pulling up the plants and piling them on blankets, where the seeds are rubbed out by hand as soon as the plants are gathered. And after being dried and winnowed the seeds are parched and ground into a meal that is similar to the *gofio* of the Canary Islanders, and is used for food, in the same way, by shepherds in the mountains or travelers on the road.

Weeds and grasses resume possession of the soil while the *cañihua* is growing, and the land is left as pasture for several years before

another "plowing" is attempted. The periods of cultivation are too short to break down the fibrous roots of grasses and other plants in the soil, so that very little erosion can take place. In favorable locations the system is permanent, and there is nothing to show how long it has been in operation or how many times the sod has been turned. Uncounted generations have lived in the highlands, and as much labor may have been applied to plowing with the *taclla* as in building the walls, terraces, artificial lands, and aqueducts for the

more striking system of agriculture that was developed in the intermediate valleys.

That northern Europe may have passed through a stage corresponding to the foot-plow agriculture of Peru is suggested by the survival of a similar implement in the Hebrides and along the west coast of the Scotch Highlands. The Gaelic name, *caschrom*, is explained as a compound of *cas*, foot, and *chrom*, crooked, and is defined in the Standard Dictionary as "a highland pick



FIG. 1.—The *caschrom* or foot-plow of the Hebrides, from Mitchell's "The Past in the Present," page 113.

or bog-hoe for stony ground. Called also foot-plow and crook-spade." As described and figured by Mitchell¹ the *caschrom* is essentially similar to the *taclla*, in spite of several differences in detail, such as a longer point, a more distinct curve near the base of the handle, and the lack of a separate hand rest, in addition to the foot rest. The mechanical principle is the same, the use of the weight of the body in breaking the soil. It might be said of the *taclla*, as of the primitive European implement, "the work which the *caschrom* does is neither contemptible in quantity nor quality, and there has gone brain to its contrivance."

The Peruvian foot-plow agriculture may be said to have had a very important relation to the present agriculture of northern Europe,

¹ The Past in the Present, p. 113.

seeing that the northern nations have become so largely dependent upon a Peruvian plant (the potato), the same crop that was the chief basis of foot-plow agriculture in Peru. That the laborious native system of plowing the potato lands has survived the Spanish conquest is easy to understand, since the Spanish colonists had nothing better to take its place. Spanish methods of plowing with oxen are now in general use in the dry intermediate valleys of Peru, where maize and wheat are the principal crops; but these methods are poorly adapted to the sod-lands of the potato belt in the higher altitudes. The primitive plows of dry Mediterranean countries serve merely for breaking and stirring the surface soil, not for cutting and turning a tough sod. Even a name for sod seems to be lacking in Spanish. The Quichua word is *champa*, but in Quichua-Spanish dictionaries *champa* has to be explained as "turf of earth with roots" (*cesped de tierra con raices*), or "clod of turf" (*terron de cesped*).

Although the potatoes and the other Andine crops are not confined to the soils that have to be broken by the foot plow, this implement may well symbolize the agriculture of the highlands. A special problem was presented by the mountain grasslands, and was solved by means of the *taclla*. The native hoe, or *lampa*, sufficed for the agriculture of the intermediate belt, and the axe or the cutlass for the milpa system of the more tropical valleys where new clearings are cut and burned each year. The foot-plow system is like milpa agriculture in that the land is planted only at intervals, but in other aspects—climate, soils, crops, implements, and methods of farming—it is widely different.



FIG. 1.—THE TACLLA OR PERUVIAN FOOT PLOW AND THE METHOD OF HOLD-
ING AND USING IT.

From the National Geographic Magazine.



FIG. 2.—FALL-PLOWED FIELD AT THE UPPER LIMIT OF CULTIVATION, ABOUT
14,000 FEET. PASS OF LA RAYA, SOUTHERN PERU.

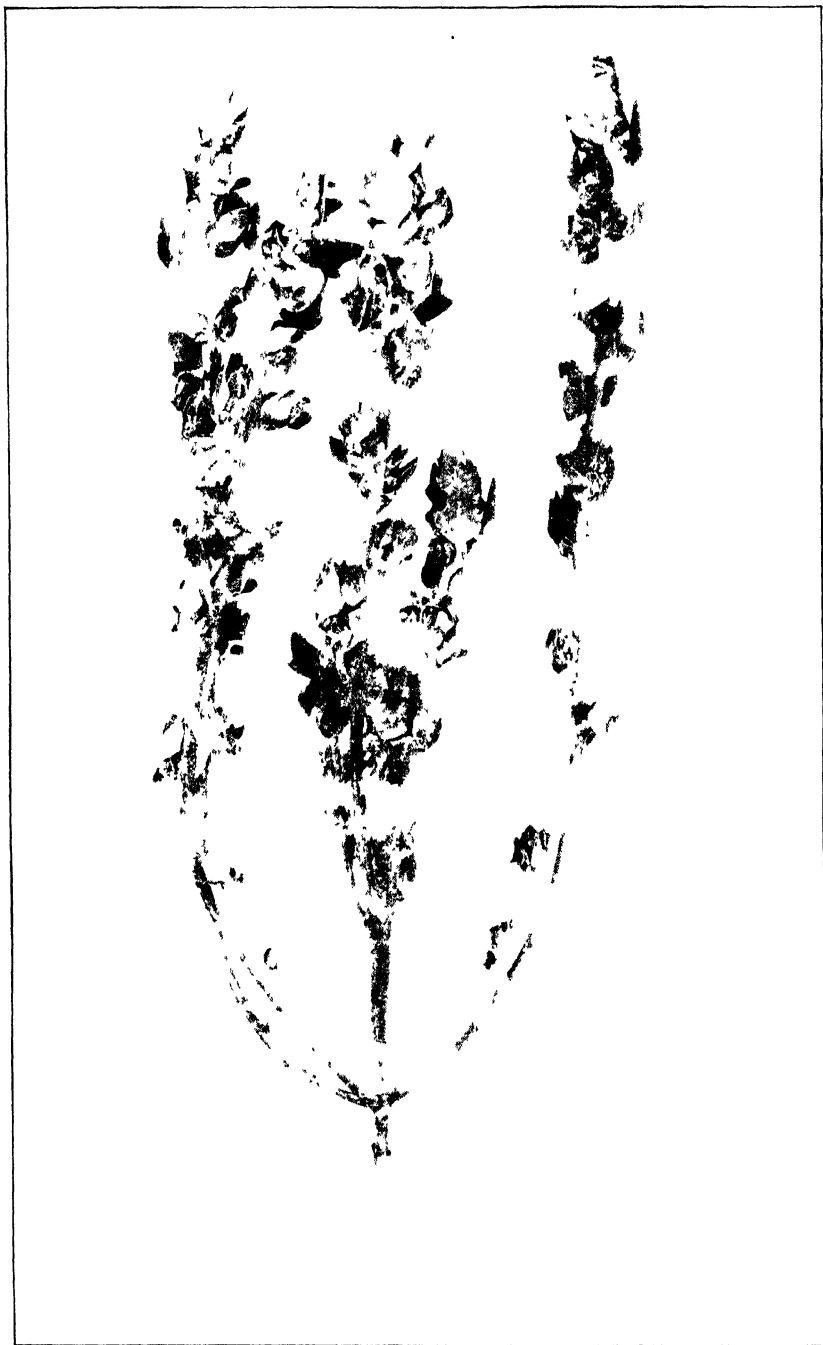


A GROUP OF NATIVE HOUSES AT THE UPPER LIMIT OF CULTIVATION, PASS OF
LA RAYA, SOUTHERN PERU.



A BITTER VARIETY OF POTATOES CALLED TUTU, GROWN AT THE HIGHEST ALTITUDE, NOT EATEN IN THE NATURAL STATE, BUT DRIED INTO CHUÑOS. NATURAL SIZE.

From the National Geographic Magazine



A RATHER LARGE PLANT OF CAÑIHUA, A SPECIES OF CHENOPodium, PLANTED AFTER POTATOES, AT THE UPPER LIMIT OF AGRICULTURE. NATURAL SIZE.

SUN WORSHIP OF THE HOPI INDIANS.

By J. WALTER FEWKES,
Chief, Bureau of American Ethnology.

[With 11 plates.]

So far as can be judged from ceremonies, the Hopi religion, so called, is materialistic, and the object of the rites is to secure food and material blessings. There may be another and deeper meaning, but this is of no concern at this time; the object of this article is to discuss their sun worship from an exoteric point of view.

The Hopi are an agricultural people, their main food supply being maize, or Indian corn. The rain, snow, and hail which water the earth fall from the sky; without moisture the corn withers and yields no harvest. The power that causes rain to fall is elemental and regarded as supernatural.

The seed corn must be planted, for it does not grow save in the earth. There is a power in the earth that makes corn sprout, but this power is connected with that of the sky. In other words, there are two cosmic agencies that appeal to the farmers—the sky and the earth. These are magic powers to which are assigned sex, male and female, and the Indian, knowing that to a union of sexes he owes the birth of his own life, ascribes the origin of all life to the same powers.

The essential necessities in the life of an agricultural people are that the sun may warm their farms and the rain may adequately moisten them; that seeds committed to the earth may sprout and grow until the harvest. Maize being the national food of the aboriginal inhabitants of Hopiland, their life depending on the success of their crop of corn, it was early recognized by these people that the force which fertilized and watered the growing corn was the sky. These powers were not understood; each was a mystery; imagination conventionalized them and made them supernatural. It would certainly be logical to ascribe growth and fructification of crops to rain, since when water failed the growing plants withered and yielded no harvest. The heat of the sun was naturally associated with fructification, for the seed buried in the earth would not grow without a warm earth, and the sun warmed the earth. What more natural than to suppose that the analogy of the birth of life from male and female elements existed in all nature, and to associate sex with these

two great magic powers of nature—the sun with the male and the earth with the female element. With this fundamental idea firmly fixed in the human mind, in time myths would cluster about these conceptions; the imagination through poetry would define them objectively until science should lead to rational explanations. When once symbolized or conventionalized they became more and more complicated and took a strong hold on the primitive mind. In the absence of realism a knowledge of causation due to direct observation was of slow growth. The magic powers of earth and sky were personated, and when once personated the possibility of man influencing these personations arose in the human mind, and with it the belief that man could control them by a more powerful magic. Influenced by this belief, he invented many ceremonies, which as time went on also became more and more complicated. These ceremonies not only increased in complication but also derived much from myth, surviving in modified form even into an epoch when changed culture has rendered them little else than folklore. Stripped of the incrustations of time and modifications due to locality, two great objects stand out prominently in the Hopi religion, viz, growth of crops, by which is understood the fertilization of the seed, and abundant water and warmth to make the plants grow to maturity.

Climate is then the all-important factor in religious beliefs and practices of the Hopi. They recognized its connection with the sun's motions and devised a method of determining accurately by observations of the position of the sun on the horizon, the time for planting and the period of the rainy season. This constant observation of the sun naturally led them to what is ordinarily called sun worship. The sun itself is not worshiped, but in their minds became a symbol, a representative of powers back of the sun controlling meteorological phenomena. This power when personated by an anthropomorphic symbolism is called by various names as the "Heart of the sky," or the magic power of the sky. There clusters about this conception of primitive man many other secondary ideas, some of which are incomprehensible to the civilized mind with a more exact knowledge of cause and effect.

We know that rain in clouds is water evaporated from the earth, falling on account of changes of temperature in the air. The primitive man did not know this. Our scientific explanation of lightning is that it is the result of electrical difference in tension. The mind of primitive man had no such idea. The primitive agriculturist ascribed forces of sky and earth to supernatural magic powers, and from their influence upon the life of the agriculturist these powers are regarded as above all others; sky and earth are considered parents of all life. It is not possible for scientific men of our century to analyze all the conceptions of the Sky god in the Hopi mind, but by

presenting instances of symbolic personations I shall endeavor to throw some light on the nature of sun worship as it now exists among the Hopi.

There are at least several kinds of data from which we can interpret primitive conceptions of worship, among which are current mythology, symbolism, and descriptive legends. For instance, when the Sky god is personated, he wears prescribed paraphernalia, as a mask painted with certain symbolic designs, and carries certain badges or other regalia. We can interpret his supposed character by his dramatic acts and relations to other supernatural beings when personated in ceremonials. In myths of the Sun god there have been passed down explanations of their rites by earlier devotees, which are crystallized by sacerdotal additions or philosophical definitions modified by the mentality of more modern thinkers.

It is evident that these mythological stories and ceremonial survivals among primitive people are based on symbolic and analogical rather than scientific conceptions, for in the growth of exact knowledge each generation somewhat modifies the myths of its predecessors, immediate or remote, to suit new conditions of life, evolved in the evolution of religious thought; consequently mythology, so called, is in a state of continual flux so far as explanation of ceremonies is concerned, and its present form may be unreliable as a means from which to determine the earliest or the characteristic ideas of antecedent primitive people.

One means of arriving at a knowledge of past beliefs is the survival of prehistoric ceremonies and cult objects handed down from the past. The rites of the people are subject to slow changes, and these modifications are not as rapid as the myths, mainly because of the secrecy surrounding them, augmented by the conservatism of an original priesthood which tends to preserve them in their purity. But myth and rite form the woof and the warp of religious development, and it is advantageous, on the very threshold of the study of sky worship among the Hopi, to measure the relative importance of mythological evidence and that of surviving rites. In the present article I have discussed the latter data.

The existing ritual of the Hopi Indians is a complex, composed of several units, possibly borrowed, but distinct from each other. The rites of different units are unlike in details, but have forms of nature worship and certain other cults in common. Sun worship is a common element in this mosaic ritual, but its character varies in complexity as well as in distinctive features in the component units. To comprehend the character of sun worship it may be well to refer to certain modifications in each component group.

Both myth and rite furnish evidences that the highest form of sun worship among the original Hopi was introduced by groups of peo-

ples from the South—virtually from southern Arizona. Legends say that these southern people, called the Patki, introduced into Hopiland the serpent sun cult, a higher form of religious symbolism than that previously existing.

The cult of the Snake people and other northern clans which settled the Hopi towns before the Patki came emphasizes ancestor worship, sky and earth playing a subordinate rôle in its ceremony. Their appeal to nature powers is through ancestral beings, represented by reptilian descendants of a culture-hero or heroine, brought into the town for that purpose in their great annual festival. Sky worship with them was secondary, or at least they have no symbolic personation of the Sky god. Among the southern clans agriculture had become the main occupation in the food quest long before they came to Hopiland, and with them prayers were made directly to the sky and earth as powers that cause the crops to grow. Both their myths and ritual deal more with cosmic powers, showing a high development of aboriginal worship.

Two positions of the sun on the horizon, at his solstitial rising and setting, the former at the end of June and the latter at the close of December, mark occasions of elaborate solar ceremonies. The time is determined by the Sun priests of the Patki people. It has been found that the former event is directly connected with the advent of the rainy season, and the latter marks when the sun reaches his most distant point to the south, at a time when the great cold intensifies the growing fear of the people that he is about to depart from the earth never to return. The departure of the being to whom the farmer owes his crops must be prevented, he must be compelled to turn back, or, as poetically expressed, the malign influences of the winter—personated by a hostile being—must be offset that the Sky god may return. In midsummer all known magic must be exerted to compel the Sky god to water the fields that the corn may grow and ripen. In both cases the sky power must be compelled¹ to aid the farmer. For want of a better term we call this process prayer, but it is more than a verbal entreaty, it is compulsion by sympathetic magic, and may be expressed in several ways, one of which is by mimetic representation called dramatization.

In rites performed at the two periods above mentioned a participant personates the sun, and others represent supernatural beings to whom the needs of the worshipers are addressed. The personators are clothed in the dress and carry the paraphernalia that in Hopi legends are associated with these supernaturals. They

¹The word is used advisedly. A priest by magic may compel a supernatural to do what he wishes.

perform dramatic rites, which indicate what the priests want, and the accompanying songs or verbal prayers are those which are considered efficacious, having been passed down from a remote past for that end.

Let us take for illustration the elaborate sun rite that occurs at the winter solstice, near the end of December. The date of this celebration is determined by the Sun priests, who watch the course of the sun as it daily sets on the western horizon, retreating farther and farther south, as if to withdraw altogether. Each day its altitude at noon is less as its setting is more and more to the south; the sun is evidently slowly departing from the earth. When it reaches its most distant southern point and sets behind the San Francisco mountains in the notch at Eldon Mesa, an official announcement is made through the town crier that the sun has descended into his house in the west. This from experience they know is the time when a supreme effort must be made to offset the power which is driving him away from his children and then the priests must use all their magic medicine to cause the sun to return to his people. The sun's efforts to return are then most feeble, and must be augmented by all the supernal powers of which man is capable.

The most important rites connected with "calling back the sun" are held in secret, on which account they occur in a ceremonial chamber called a *kiva*, to which only the initiated have entrance. This room is occupied by men belonging to the Sun clans, and by others, mainly old men, called Sun priests. A detailed description of the altar (pl. 1) and other paraphernalia in the *kiva* at this dramatization need not be made, but a few general features may be mentioned. At one end of the room, near the ceremonial opening in the floor called the *sipapu*, there is erected an assemblage of objects which may be called an altar, composed of an elaborate framework, to which are attached painted circular disks made of gourds, representing flowers. These symbols form a screen,¹ behind which some of the actors conceal themselves.

In the middle of this screen there is left an opening through which protrudes a head of a serpent effigy. On the floor in front of it are arranged various objects, the most conspicuous of which is a stack of corn ears, future seed, neatly arranged in a pile. Here are also certain emblems and paraphernalia belonging to the priests, among which may be mentioned a badge or palladium of the Patki priesthoods, their medicine bowl, a prayer meal basket or tray, and various fetishes. Before the screen stand masked men representing certain supernaturals, and along the sides of the room sits the chorus

¹ The Winter Solstice Ceremony at Walpi. Amer. Anthropologist, n. s., Vol. XI, pl. 1, 1898.

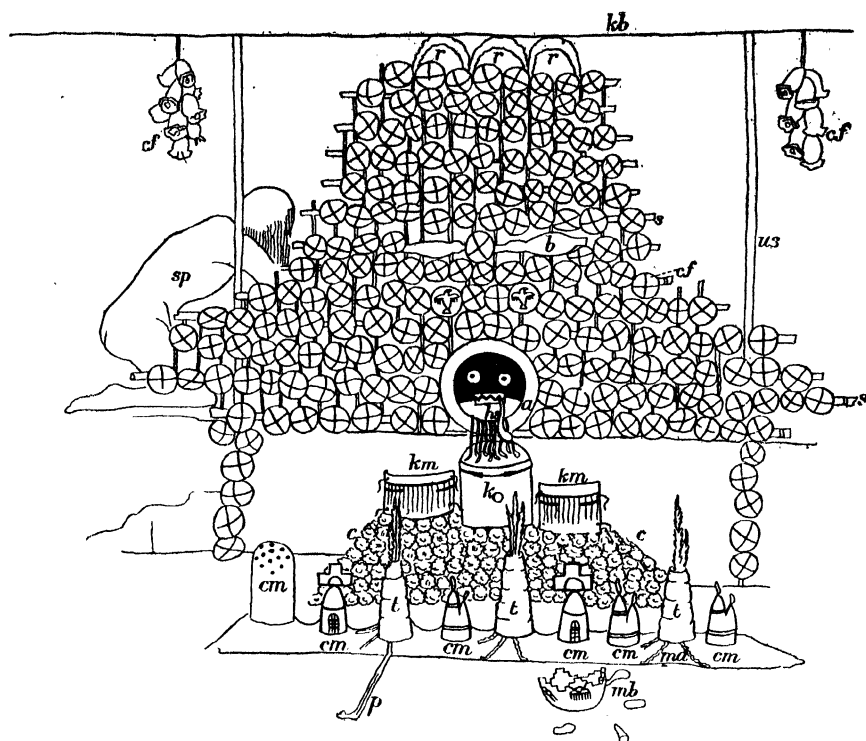
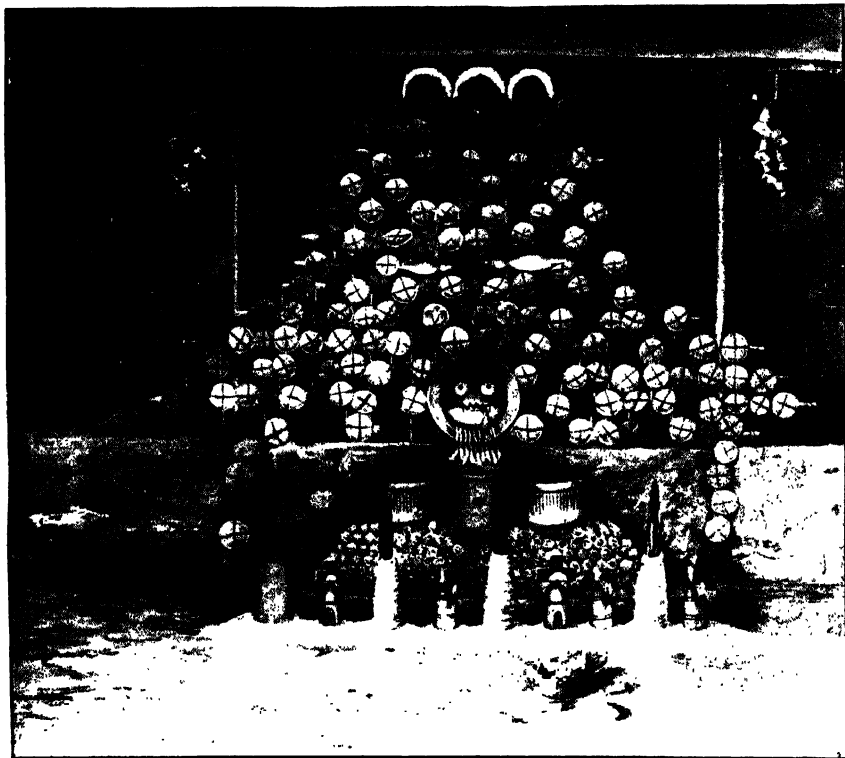


PLATE I. ALTAR OF THE WINTER SOLSTICE CEREMONY AT WALPI.

- a*, Disk through which great serpent effigy protrudes.
b, Bird fetish.
c, Bank of seed corn later distributed to clans.
cf, Flowers of vegetation, corn, melons, and squashes.
cm, Corn mounds or germ fetishes. One, at left, has holes for corn flower symbols.
hs, Head of Horned Serpent.
k, Mask of Sun god or Sun kachina.
kb, Kiva roof beams.
km, Masquettes of Corn maids.
mb, Medicine bowl.
p, Line of meal along which blessings pass to village.
r, Rain cloud symbols.
s, Lateral framework supporting the altar screen.
sp, Man blowing trumpet, imitating roar of Horned Serpent.
t, Tiptonis or badges of chiefs of the ceremony.
us, Upright beam supporting the altar screen.



ALTAR OF THE WINTER SOLSTICE CEREMONY AT WALPI.

who sing songs to the accompaniment of rattles and say the appropriate prayers as the occasion requires.

The ceremony or drama before this altar opens with a formal smoke by the chiefs, in which, with due reverence, a lighted tobacco pipe is passed with great solemnity from one priest to another, seated about the fireplace, after which steps are heard on the roof of the room, indicating an important arrival. Soon a small ball of sacred meal thrown through the hatchway of the roof lands on the floor by the side of the fireplace, by which the arrival of the god is formally announced. The visitor is invited to enter. Cries of the eagle have been imitated for a long time by a man seated in one corner of the room blowing through a bone whistle into a bowl of medicine. These cries or calls to the Sky god now become louder than ever, and soon the visitor appears in the hatchway and descends the ladder through the roof. He is welcomed into the room and is seen to represent a large bird, wearing on his head a bunch of feathers attached to a leather helmet made in imitation of a bird's head. The disguise is not limited to the head, for his body is daubed in spots with piñon pitch, to which are attached feathers, while across his shoulders is stretched a string to which are tied rows of feathers in imitation of wings which he flaps up and down, mimicking the motions of a bird. Thus appareled he struts around the room, imitating a bird in gait and in the movements of his wings, at times emitting calls like those of a hawk or eagle. This personation represents the Sky god, whose advent is the return of that supernatural.

In one corner of the room, at the right of the altar, sits a maiden apart from all others, who represents the Earth maid. On the floor in front of her there is a pile of sand a few inches high, in which are stuck a few short sticks like arrows. After the Sky god has made several circuits about the room, during which he is the recipient of many prayers from the assembled priests, he halts and squats directly in front of the girl. Bending down his body almost to the mound, he takes from it in each hand an arrow, and then raising his body with a cry, throws them back into the pile of sand. Having made another circuit of the room, always sinistral in direction, he returns to the girl, repeating the act several times. The meaning of this performance is not hard to discern; it represents the fertilization of the earth, as symbolized by the girl, by the lightning as symbolized by the arrows. The act is a declaration that man desires the god to fructify the earth and thus to bless them with abundant harvest.

The object of this winter solstice ceremony is not only to draw back the sun, the arrival of whom, as we have seen, is dramatized in the rite just described, but likewise to impart new life to all

nature, to fertilize the earth, that the Germ god may vitalize not only the crops, the seeds of which are piled below the altar, but also all game, domestic animals, and human beings—material resources of all kinds. The winter solstice rite is a complex prayer to the Sky god to return and renew life.

The horned or plumed serpent is a symbol of the Sky god and this being brought to Hopi by southern colonists is consequently symbolized in the winter solstice ceremony introduced by them. It occupies a prominent place in the rite in which the return of the Sun god is dramatized, and its idol or effigy is the most conspicuous feature on the above mentioned altar. Directly after the celebration of the arrival of the Bird god each worshiper says his prayer to the serpent idol, the head of which occupies the opening in the screen of flowers, and sprinkles it with sacred meal, as is customary in prayers. They regard this serpent effigy as a personation of the Sky god, or as the renewer of life, as the bird man whose actions have already been described represents the sun.

But to study this element of sky worship in its more elaborate drama we should visit the kivas at the vernal equinox, near the planting time, when there takes place perhaps the most remarkable ceremony yet described among the Hopi or any aboriginal tribe of North America.

The description given above indicates the character of the Sky cult by one component of the Hopi in the winter solstice ceremony at Walpi, but the fertilization ceremony with very significant variations occurs at other Hopi pueblos. We have observations of this rite at Oraibi, where the intention is identical with that at Walpi, although the horned serpent effigy is not introduced. Here elaborate sun ceremonials, in which the Bird man plays a prominent part, are duplicated, although modified in details. In addition, there are certain rites performed at this time at Oraibi which appear in a modified form at Walpi. The most significant of these is the introduction of a portable screen, on which is painted the counterpart of the sun, the Germ god, before which are performed ceremonies for the fertilization of corn. The screen used at this time is a rectangular frame, over which is stretched a cotton cloth bearing other designs in addition to the figure representing the Germ god (Alosaka). The lower part of this screen under the figure is covered with corn seeds. On one side of the central figure is a design representing the sun; on the other a picture of the moon, above which is a well-painted corn plant. To the top of the screen are attached semi-circular hoops covered with cotton wool, symbolic of the clouds.

The ceremonies about this screen are too elaborate to be described in detail, but their main object is the fertilization of corn, represented by the kernels attached to its lower part. In the progress of the rite

these seeds are scraped from their attachment to be used in future planting. During the songs an invocation is sung to the Great Snake, although no effigy or other representation of him is used at that time. Shortly after this rite, absent at Walpi, there appears in the kiva a personation of the Sky god wearing on his head a star with four points, the "heart" of the sky. He carries in his hand a disk upon which is painted the sun emblem, to the back of which is tied a planting stick. At the most solemn time in the rite this personator twirls the sun emblem in his hand, pointing it in succession toward the cardinal points.

In reviewing these rites with a view to interpretation and comparison with the Walpi variant, it appears that the main object is the same as the rites in which the effigy of the snake is used, or fertilization of the seed. The Sky god, symbolized by both sun and horned serpent, is the beneficent Sky god who fertilizes the seed, brings the rain, and causes the crops to grow. It thus appears that the functions of the Great Serpent and the Sky god are intimately connected in Hopi philosophy, the difference of personation in dramatization being largely due to modification in the different pueblos, possibly from the predominance of different clans.

It is evident that there are two essential features or two elements involved; first, the fertilization of the earth and, second, the renewal of life, especially of the food plant, corn. The production of rain is not the striking motive in this complex ritual, but rather the procuring of the needed warmth and moisture upon the seeds to cause growth and furnish a food supply. From one point of view the falling rain fertilizes the earth and makes the crops grow, so that we may say there is only one object in these rites, namely, that of fertilization.¹ The Sun and Great Serpent, symbolic forms of the Sky god, impart the principle of life, as in many other ceremonies among the Hopi.

The Zuñi have an equivalent of the Hopi horned serpent, whose effigy, mechanically attached to tablets on which rain clouds are depicted, is brought into the town and carried to the entrance of each kiva. The head of this effigy is held over the kiva hatchway, while water with seeds are poured through the body, emerging from the mouth into receptacles held up to receive them—an act symbolic of water and seeds for the coming planting time, the gifts which the Great Serpent brings to the Zuñi. To still further show that the Hopi serpent effigy is a god of fertilization it may be mentioned that attached to the backbone of its body there is a quartz crystal, symbol of the sun, and specimens of all the different kinds of seeds known to the Hopi. The intention of the Great Serpent worship in both pueblos

¹ cf. H. K. Haberlein, *The idea of fertilization in the culture of the Pueblo Indians*. Mem. Anthropol. Assoc., Vol. II, No. 1, pp. 1-55.

is practically the same; it refers to the Sky god symbolized with minor differences in paraphernalia but introduced for an identical purpose. The Hopi, like the aborigines of Mexico, Central America, and the West Indies, revered the Great Serpent and worshiped the supernatural he represents as a beneficent being, who brings life, much needed rain, and other blessings. The serpent with them was not a devil or a personation of moral evil.

Shortly after the close of the act that celebrates the arrival of the Sky god there occurs at Walpi a dramatic representation of a conflict of supernatural beings, supposed to be hostile. This takes the form of a realistic fight between men appropriately clothed to personate these beings, lined up on each side of the room, while a man representing a supernatural being stands in the middle of the kiva before the altar. As his opponents, ranged in two rows, one on each side, surge up against him, a spirited song is sung by a chorus, beginning with a low-intoned chant, that gradually rises in intensity until it becomes a war cry. Each participant has depicted on the shield he carries a figure of the being he represents. The man before the altar carries a shield with a picture of the Germ god (pl. 2); his opponents, various other designs. The contest begins by one of the attacking party pressing forward against him, as if endeavoring to overcome him. Back and forth for a considerable time the combatants surge, each endeavoring to overthrow his opponent. Finally the attacking man falls to the floor overcome by sheer exhaustion, and in that condition is carried out of the room. A second opponent then advances and he, too, is overcome. This is repeated until all the opponents have been overthrown, some being removed from the room in an exhausted condition. The man bearing the shield is victorious over his enemies. During this combat there is much shouting and what appears to be great excitement prevails, much of which is, of course, feigned. At the close, the triumphant man, holding his shield high above his head, says a prayer, the purport of which is a declaration of victory over all comers, or a taunt to any others who question that claim. As the excitement subsides, he leaves the room.

The explanation of this event is not wholly obvious, but the combat suggests the conflict of hostile nature powers, and recalls certain rites among the ancient Aztec people.

It should be borne in mind that these events take place at night in a closed room, from which the people are debarred. There remains to be considered an event that occurs at dawn the next day, when the arrival of the Sun is dramatically represented in the presence of the people. At sunrise there enters the pueblo a masked person bearing symbolic paraphernalia ascribed to the sun, accompanied by two men dressed as women, each bringing a flat basket tray in which ears of corn set on end are arranged in a circle in-



ALOSAKA (GERM GOD) ON SUN SHIELD IN WINTER SOLSTICE CEREMONY.

Horsehair stained red generally found on the periphery of sun shields is here omitted.

closing symbols of sprouting vegetation. As this trio passes through the village these symbols are distributed to the head of each clan. Many rites in addition to those above mentioned are performed, but those described illustrate the more important phase of the drama—the combined efforts of the Sun worshipers to overcome hostile powers, to halt his departure, and to renew life, thereby insuring the growth of the corn.

The rôle that sun serpent worship plays among the Hopi may be more clearly understood by an examination of another celebration of the Patki clans occurring at the end of March, near the vernal equinox. So close is this to a theatrical exhibition that it is difficult to determine whether it is a religious or a secular observance. Originally, probably, it was the former, but the personations in it are so striking that it has been modified into a secular performance. A special article¹ has already been devoted to the different acts, six in number, which last from sunset to sunrise the next day.

The setting of the horned serpent scenario at the vernal equinox at Walpi is quite different from that at the winter solstice, although the effigies of this monster are identical in both ceremonies. During this celebration we have a succession of dramatic performances, each of which crudely represents some cultural episode in the history of the tribe.

The events about to be described occurred consecutively in sacred rooms or kivas which at the time were occupied by spectators, the performers passing from one room to another performing simultaneously different acts in the rooms. Each room at that time had a different audience, determined by clan affiliations, crowded in the spectators' section or the raised part of the floor at one end of the chamber. The ceremonial region of the room was unoccupied save by the performers, who came and left before and after each act. During the performance the kiva chief, who controls the rites, sits near the fireplace at the base of the ladder, and feeds the fire with greasewood, the flames of which furnish the only light to illuminate the chamber. The performers bring their own paraphernalia, which they set up in the dark, the fire tender allowing the flame to go down meanwhile or covering it with a blanket that the preparations for the successive acts may not be witnessed by spectators. In the several acts that form this primitive drama many episodes in the culture history of the tribe were dramatized, but I shall consider only those in which the horned snake cult was introduced.

The first act, in some respects, is similar to the so-called screen drama of the winter solstice and is one of the most instructive. The spectators having assembled, the kiva chief takes his seat on the floor

¹ A theatrical performance at Walpi. Proc. Wash. Academy of Science, Vol. II, pp. 605-629, 1900.

by the fireplace and soon a ball of meal thrown into the room from above lands on the floor, tramping of human feet being heard on the kiva roof. The chief calls out to those on the roof to enter, at the same time covering the smoldering fire with an old blanket to shut out the light, after which the forms of men are seen descending the ladder. As they enter the room with the customary salutation they make their way to its unoccupied part and in the dim light put their screen in place and arrange their paraphernalia on the floor. At a signal from them that they are ready to begin, the chief removes the covering from the fireplace and before the astonished gaze of the audience there appears stretched across the rear of the room a cloth screen (pl. 3) upon which are painted various symbolic devices with figures representing Corn maids, Germ god, and symbolic rain clouds, lightning, and other designs. The most prominent of these are six circular disks arranged in line across the middle of the screen to which each is attached. On each of these disks is painted a symbolic picture of the sun. The screen is held upright by poles, each supported by a man, whose naked body is daubed with clay and who wears on his head a helmet covered with projections like wens. These men are the so-called Mudheads, Delight Makers, or the clowns. On the floor before the screen is arranged a miniature field of corn, each hill a clay cone, supporting a corn plant that has been grown in the kiva. Prominent among the actors before the screen is a man dressed as a woman who represents the Earth woman; there are several men with masks on which are wens or knobs representing eyes, mouth, and ears. Others similarly appareled are squatted by this screen along the sides of the room. Behind it are men who manipulate the serpent effigies soon to be described.

The effigies of the horned serpent used in this rite are like that of the winter solstice ceremony; a few words regarding their construction may be instructive. Each serpent has a head and body; the former a gourd, the latter made of cloth appropriately painted and stretched over rings, the size of which increases from the head backward. The so-called backbone to which the head is attached is a stick by which the idol is manipulated. It has a ferrule just back of the neck, to which are attached a bag with seeds of various kinds, a quartz crystal, and other objects. The head is made of a gourd painted black, in which the mouth and teeth are cut, the lips being painted red; from the mouth there protrudes a strip of red painted leather representing a tongue. The eyes are bundles of seeds done up in buckskin protruding like goggles from the top of the head, to which is also tied a bundle of feathers and a short curved horn. As the rite begins, this effigy is manipulated by a man stationed behind the screen, and is slowly protruded through the opening

covered by the sun disk, until it projects 3 or 4 feet in front of the screen.

The act opens with a song by the chorus, and as it progresses the six disks bearing the sun emblems, which are seen to be hung by a hinge on one side, swing open from below. As they do this there protrudes through the openings the blackened heads of six effigies of the great serpent, one of which, larger than the others, has udders and is called the "mother serpent." As the songs begin, these effigies move their heads back and forth, darting at each other as if attempting to bite their neighbors, while from the rear of the screen issue sounds made by concealed actors imitating the fancied roar of the horned serpent. As this continues, the song rises higher and higher, and the attacks of the serpent effigies on their fellows become more and more vicious. Suddenly the head of the mother serpent sweeps down to the floor of the room over the imitation field of corn, overthrowing the hills and scattering them right and left. These realistic movements of the snake effigies are caused by men concealed behind the screen, who handle their charges by means of a stick called the "backbone." After the field of corn has been overturned and the serpent effigies raise their heads, there passes before them the man dressed as the Earth woman, who offers prayer meal as food to the enraged serpent, after which the effigies are withdrawn, the disks fall back in place, and the chief gathers up the scattered clay cones with the sprouting corn plants and distributes them among the audience.¹

The kiva chief stirs the greasewood fagots in the fire until the flame again lights up the kiva, and all is ready for the advent of another group of actors fresh from a performance in another kiva.

After a long wait another act is performed, the arrival of the actors being announced in the same manner as before described. In this act a masked man, representing the Sky god, stands in the middle of the kiva, holding in his hands the effigy of a serpent about 5 feet long. When the song that accompanies the rite begins, the snake effigy appears to crawl around the man's neck, twisting its body or darting out its head in a most realistic manner. In this proceeding the serpent is the servant of the man; it is evident that the effigy is controlled by the manipulator. Near the close of the act, when there is great excitement among the spectators and many loud cries, the effigy is made to sweep down on the floor over a miniature field of corn, skillfully arranged on the floor in the same manner as in the preceding act.

An examination of the mechanism by which these movements of the effigy are produced reveals the fact that what appears to be

¹ The Horned Serpent is here the agent of the Sky god. The act may dramatically represent the fertilization of the corn by the Sky god.

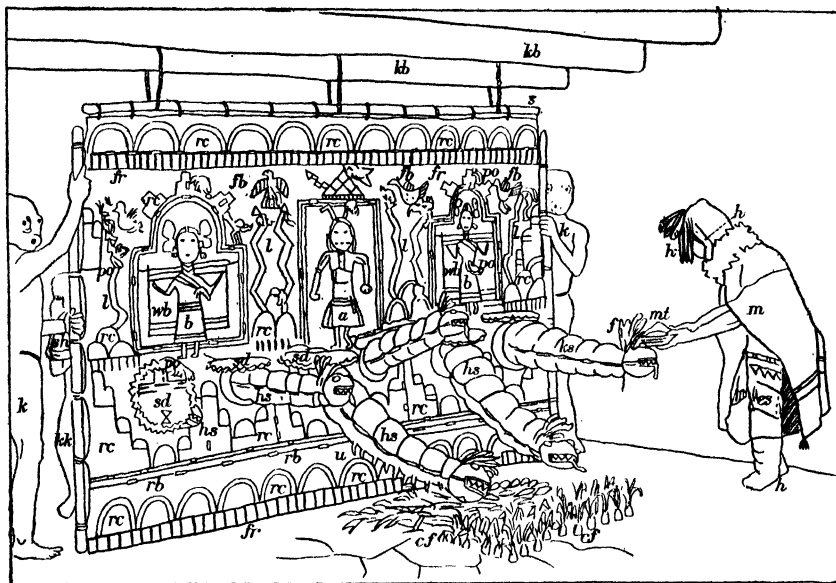
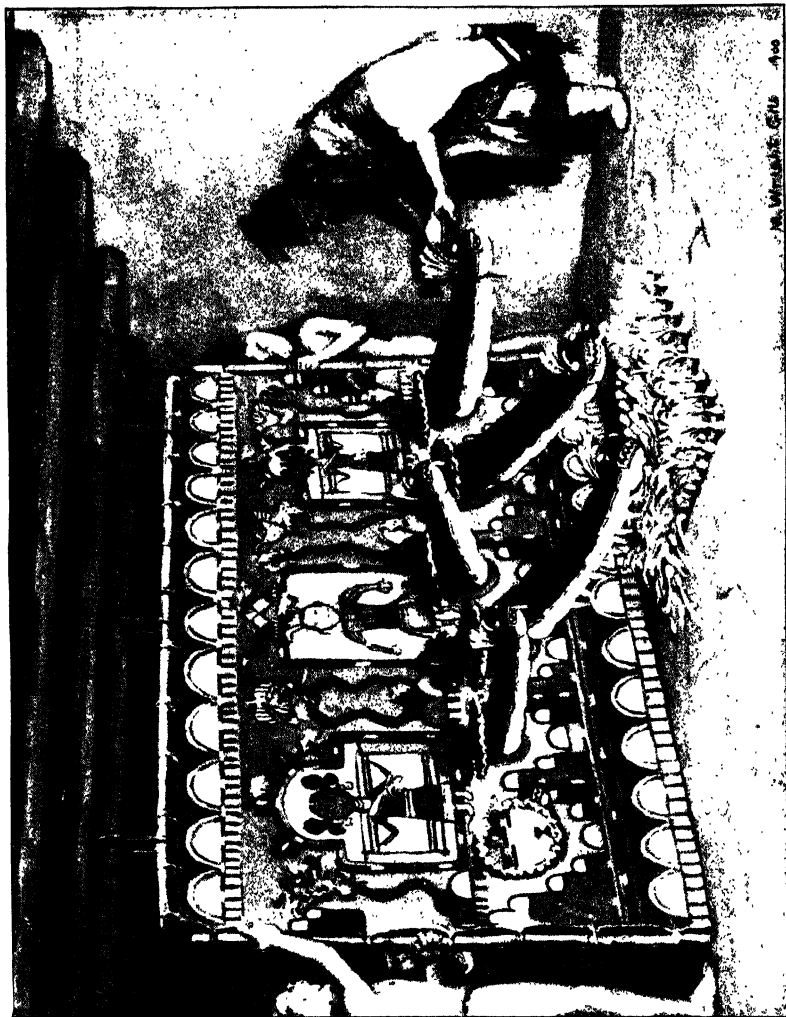


PLATE 3. SERPENT SCREEN AT WALPI.

- a*, Alosaka, or God of Gernis.
b, Corn maids.
cf, Miniature cornfield, made of sprouted corn set in clay pedestals.
cs, Embroidered katchina sash.
f, Hawk feathers.
fb, Unidentified bird.
fr, Rain symbol.
h, Hahaiwuqti, mother of living beings; Earth goddess.
hs, Horned Serpent effigies.
k, Mud heads, personations of ancients.
kb, Beam of kiva roof.
kk, Man blowing trumpet to imitate roar of Horned Serpent.
ks, Extended serpent effigy being fed by mother of gods.
l, Lightning symbols.
m, White ceremonial blanket.
mt, Tray of prayer meal.
po, Prayer offerings.
rb, Rainbow symbols.
rc, Rain cloud symbols.
s, Frame supporting screen of the serpents.
sd, Symbol of Sun.
sh, Shell or gourd trumpet used to imitate roar of the Horned Serpent.
u, Udders of the mother Horned Serpent.
wb, Ceremonial blanket



SERPENT SCREEN AT WALPI.

the left arm of the man apparently hanging naturally at his side is a false one, the man's real arm being extended into the body of the serpent through a slit in its back; his hand grasps a stick which forms the backbone of the reptile. The signification of the proceeding is evident. The personator is the Sky god with his servant the lightning.

In another act, in the series performed at the vernal equinox in Walpi we have the episode of the "Mudheads" struggling with a serpent effigy protruded through an opening closed by a disk on which is depicted the sun symbol. The performance is shown in plate 4.

If not too tiresome we may consider another act in this series of weird dramatizations. It is recorded in legends that at one time the Great Serpent rose in the middle of the court of an ancient village until his head projected to the clouds. As this monster emerged from the earth he drew after him an overflow of water that covered the whole land, and drove the inhabitants to the mountains. When a flood covered the earth, the chief of the village, speaking to the serpent, whose head was in the zenith, said "Why do you thus destroy my people?" The snake replied, "You have a bad man, or wizard, in your number who bewitches you. I will not return to earth until you sacrifice to me your son." Sorrowfully the chief followed this demand for the relief of his people and threw his son into the water, and the serpent sank into the earth, dragging after him the flood that he had brought. Upon this legend is based the act of the Hopi drama at the spring equinox, which is dramatized as follows:

After the same preliminaries that precede other acts, while the room is dark, a new set of actors descend the ladder and place on the floor near the ceremonial opening two pottery vessels (pl. 5), on the sides of which are painted pointed star emblems, symbolizing the sky god. The openings of these jars are closed with semicircular flaps, four in number, attached to the rims of the vessels. The chorus, seated around these vessels, are the clowns who wear hideous masks covered with clay balls; they are supposed to represent archaic men who peopled the earth before the advent of the present race. This act, like the others, is accompanied throughout with song; and as the singing rises in volume there emerges from each jar the head of a serpent effigy, which mounts to the roof of the kiva, dragging its body behind it until its whole length is visible.

They do not leave the bowls, being attached to the rims. They begin to twist their bodies together and appear to bite at each other as if angry. They even bend down and sweep over a miniature field of corn arranged on the floor, after which they slowly sink back into

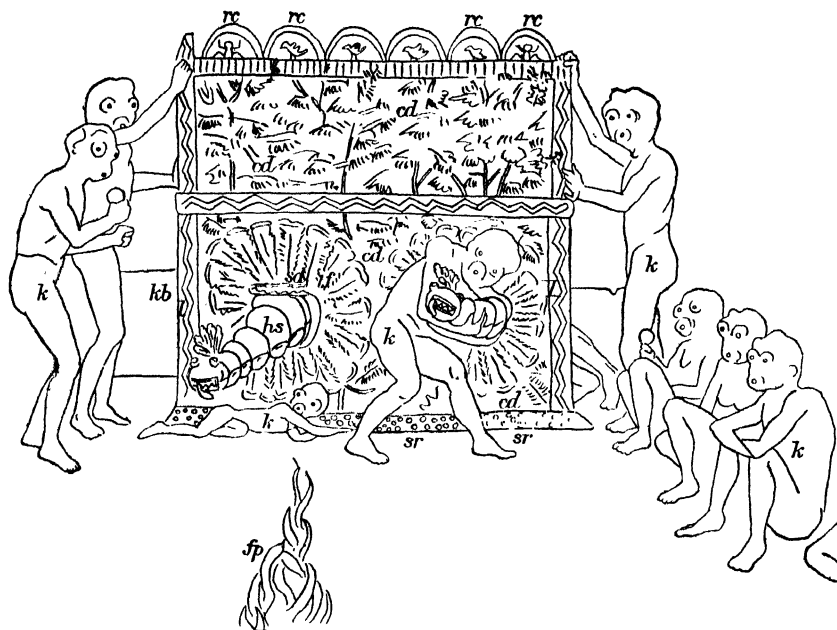


PLATE 4. STRUGGLE OF SERPENTS AND MUDHEADS.

cd, Cedar boughs concealing the man who manipulates the serpent effigies.

fp, Flame from fireplace.

hs, Horned Serpent effigies.

k, Mudheads; ancients (man and boy).

kb, Banquette of the kiva.

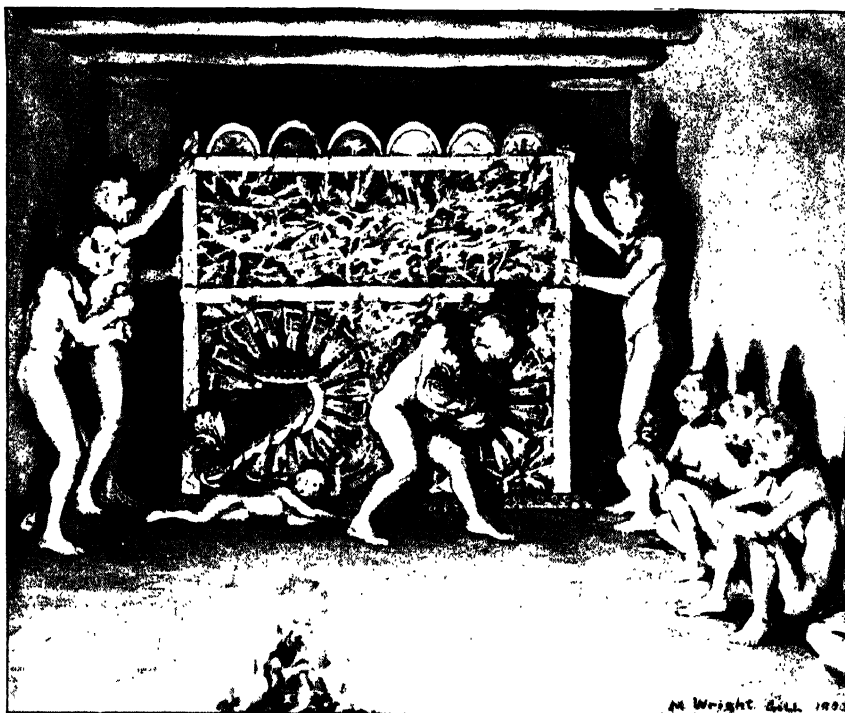
l, Symbol of lightning.

rc, Symbols of rain clouds.

sd, Sun symbol raised to horizontal position.

sr, Ridge of sand for supporting the screen.

tf, Turkey feathers.



STRUGGLE OF SERPENTS AND MUDHEADS.

the vases from which they have emerged. The means by which this is done cannot be discovered in the darkened room, but invisible horsehair or other strings attached to the heads and bodies of the effigies pass over the beams of the kiva roof, and down to the hand of the singers. While with one hand these men shake their rattles in accompaniment to their songs, with the other they manipulate the serpent in realistic movements. It is apparent that this act represents the serpent destroying the planted field, possibly by a great flood, as recounted in the legend given above.

The episode represents in a more or less complete form a myth which is said to have originated in the far south, and which is still current in modified form among the Pima and Papago, supposed to be descendants of the ancients who once peopled the massive walled ruins, of which Casa Grande is the recognized type. The horned snake represents among the Pima as among the Hopi, the Sun god, called Teuhu ("Montezuma"), who taught mankind how to irrigate fields for cultivation and to build ditches to distribute the water of the Gila over their thirsty farms. It is said that this being controlled the waters of the Gila, and that he was worshiped. A story recounts how he took a hair from his head and drawing it through his mouth laid it on the ground so that one end touched the channel through which the river now flows. He took another hair or feather and drew it through his mouth and laid it parallel to the first, and so on until he had marked out the land in sections. When that had been accomplished he spoke a word and each of these hairs or feathers became a serpent, and later an irrigating ditch. The channel of the river itself became the great serpent, "and that is why," added the narrator, "we worship the river in the form of a serpent, and on this account we make frequent sacrifices on the banks of irrigating ditches." When this cult was transported into the arid mountains of Hopi, where rivers are unknown, except in the rainy season, it still persisted, but, like many survivals, the environment and object of the worship was changed; the serpent became the rain god, or the agent of the sky, in causing rain to fall on the crops. This myth is perpetuated in the dramatic festival at the vernal equinox.

The cult of the Zuñi horned serpent, Kolowissi, has a close resemblance to that of the Hopi, suggesting that it was probably derived from the same source, or the former inhabitants of villages now in ruins along the Little Colorado. We owe to Mrs. Stevenson a description of the rites observed when the effigy of this being is carried to the Zuñi kivas, from which it looks as if the Zuñi horned serpent, like the Hopi, is an incarnation of the Sky god and has the same function. At certain times in these rites the Zuñi effigy is made to vomit water and all kinds of seed at the command of the Sky god. The Zuñi drama of the advent of the horned serpent occurs at the

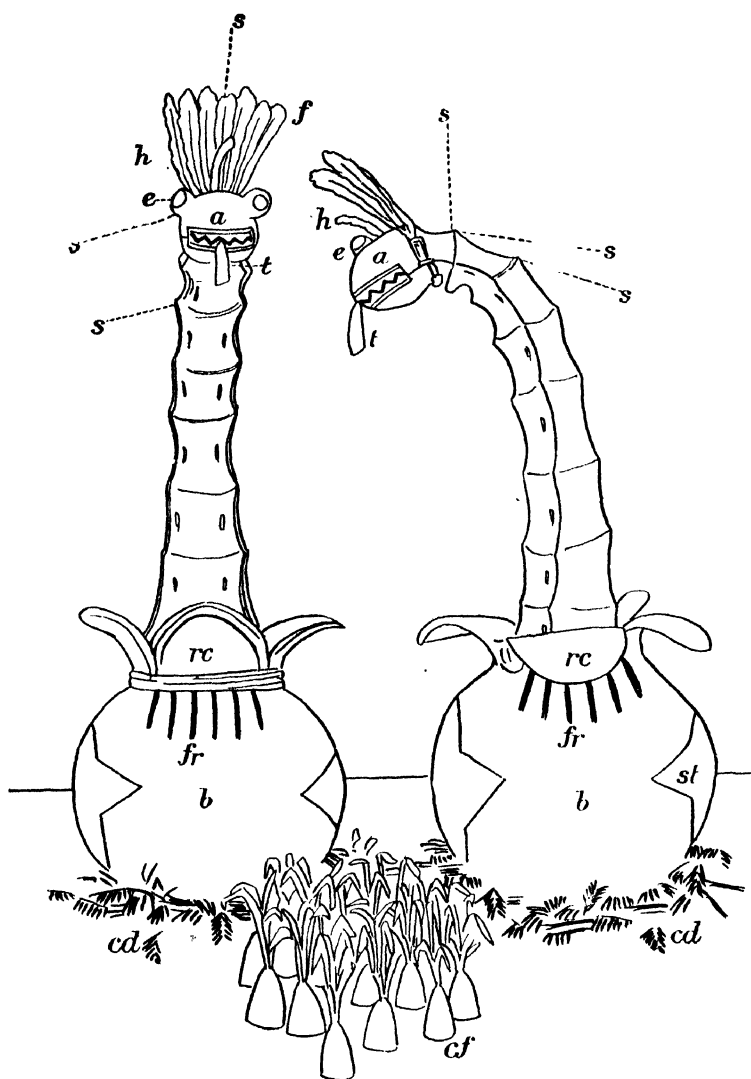


PLATE 5.—SERPENT EFFIGIES RISING FROM JARS.

a, Head of effigy of Horned Serpent.

b, Vases, receptacles for effigies.

cd, Cedar boughs.

cf, Miniature field of corn made of sprouted corn plants in clay pedestals.

e, Eyes.

f, Feathers of hawk.

fr, Falling rain painted on jars.

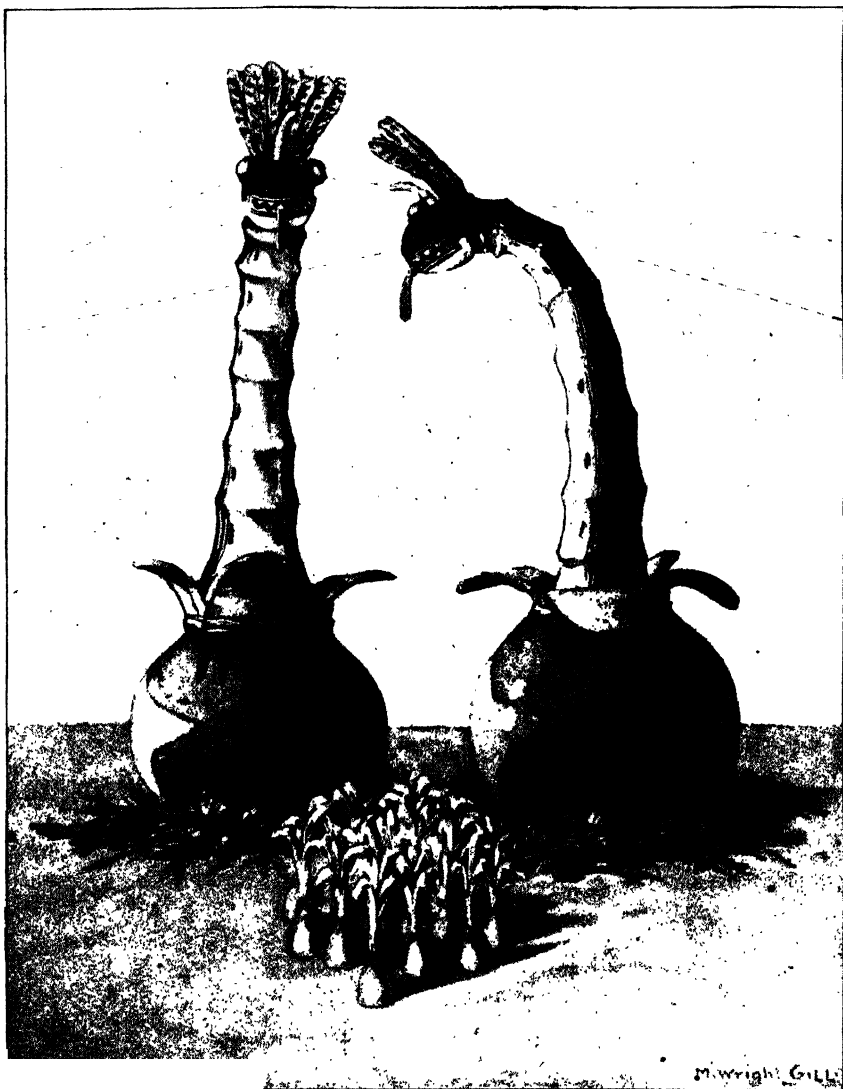
h, Horn of Horned Serpent.

rc, Symbols of rain clouds.

s, Strings used in manipulating snake effigies.

st, Star symbol.

t, Tongue of Horned Serpent.



SERPENT EFFIGIES RISING FROM JARS.*

same time the sun ceremonies are celebrated among the Hopi, and sun symbolism is prominent on the paraphernalia used at that time.

The horned serpent called Avanyu is the main idol in the winter solstice altars¹ of the Tewa pueblo, Hano, two of which are manufactured each year of clay and laid on the floor back of the sand paintings (pl. 6). Dramatic rites are performed before this altar and the sun is suggested by the stick called sun ladder (pl. 11) in the rear of the altar.

The Tewa Avanyu, like the Hopi horned serpent, represents the great power of the Sky, the male fructifying element, father of all life, personated by a clay image. The six horned serpents of the Tewa, ascribed by some authors to the different cardinal points, is a parallel conception with the six horned serpents of the Hopi. They are not different beings, but the same Sky god localized.

The worship of the power of the sky as symbolized among the Pueblos by a great plumed or horned serpent sheds a light on the reverence which the Mayas and other Central American cultures of prehistoric times paid the power they personated as the plumed serpent (Kukulkan and Quetzalcoatl) whose many representations occur on prehistoric buildings devoted to worship in Mexico and Central America. There figures of the great serpent symbolize the same great male power of nature as the rude figurines of the Hopi. Prof. E. B. Tylor has shown that Quetzalcoatl represents the sun, but the meaning of his cultus is much deeper. Quetzalcoatl symbolizes the same conception as the plumed serpent of the Hopi, not the sun alone but the great father of all life, the male fructifying power of nature of which the sun is a visible representative of an attribute.

In some of the Hopi festivals the worship of the horned serpent seems to be hopelessly entangled with another characteristic of a less highly developed culture. I refer, of course, to the flute festival and its relation to the well-known snake dance of the Hopi. This entanglement is due to mutual acculturation of the Horn, Snake, and Flute peoples, the latter of which came from the same region as the Patki people who introduced into Hopiland the plumed serpent worship. The confusion is increased by the introduction of living reptile worship in the snake dance. It is well, therefore, to consider this relationship.

There are at Walpi two great midsummer ceremonials unconnected with the great serpent cult which alternate in August each year—one, the snake dance, occurring in odd years; the other the flute dance, that is performed in even years. The former shows few objective evidences of Sky serpent worship; the latter contains many personations and symbols of that cult, due to an ancient association of the Horn and Snake clans; the union of the former with the flute clans antedating the separation of Snake and Horn people.

¹ Winter solstice altars at Hano. Amer. Anthropol., n. s., Vol. I, 1899.

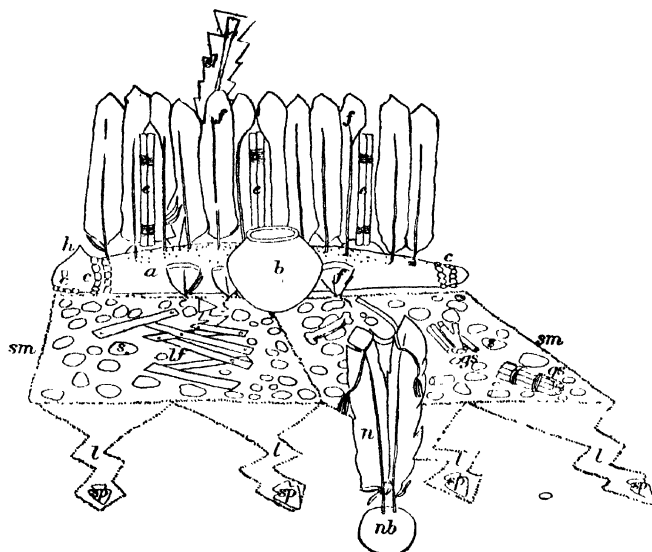
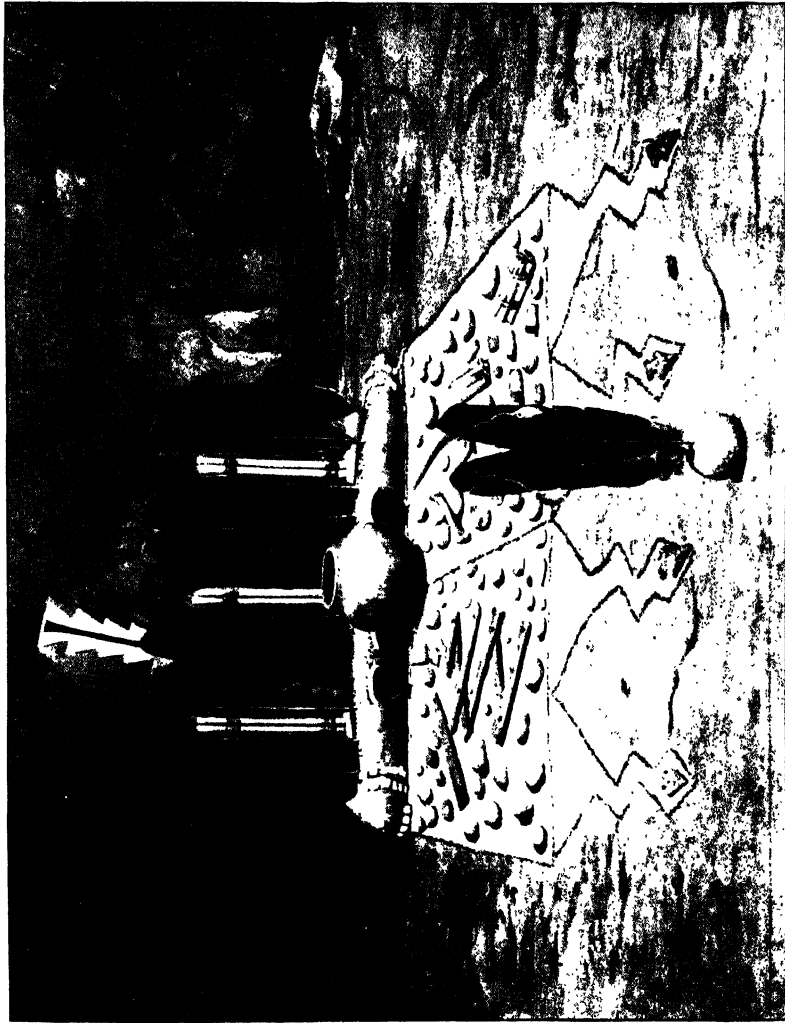


PLATE 6. WINTER SOLSTICE ALTAR OF HANO.

- a*, Clay image of the Tewa Horned Serpent.
- b*, Medicine vase.
- c*, Necklace and teeth made of corn kernels.
- e*, Symbolic cornstalks.
- f*, Turkey feathers.
- gs*, Gaming reeds.
- h*, Horn of Horned Serpent.
- l*, Lightning symbol made of sand on floor.
- lf*, Lightning framework made of wooden slats.
- n*, Eagle feathers placed at entrance to the kiva to warn away the uninitiated.
- nb*, Clay ball to support eagle feathers.
- s*, Waterworn stones used as fetishes.
- sl*, Symbol made of wood of sun ladder.
- sm*, Dry painting made of sand on the kiva floor.
- sp*, Spear or arrowhead of stone.



WINTER SOLSTICE ALTAR OF HANO.

In the preceding pages the essential elements of sun worship in the Hopi ceremonies ascribed to southern colonists and those of Hano and eastern extraction have been considered, and these may be said to represent forms of solar rites among these people; but there are still other forms of sun worship that are said to have been introduced by other people that make up the heterogeneous population. Among many others may be mentioned the so-called *Kateinas*, where we have a set of rites not as complex, but perhaps more primitive. These beings among the Hopi represent ancestral personages, or clan ancients. The sun is regarded as the father of both *Kateinas*, or those who have passed on, and men and women still living. As it is supposed that human beings that have died and now live in ghostly communities have greater powers to aid the living, they are appealed to and influenced by magical processes and they are conjured from time to time to return to the village and aid their descendants or living survivors. The occasion of their arrival is a great festival, at which, after having been prayed to, they depart for their home in the underworld, where the spirits of the dead are supposed to dwell. The dramatic representation of their advent and departure is celebrated by an elaborate dramatization, commonly called a dance, in which masked personations of these beings appear. At this time appears also a representation of the Sky god, who leads the *Kateinas* into the pueblo. As the dead are supposed to follow the setting sun to his home in the west, the entrance to the underworld, the *Katecina* departure is also dramatically represented when they leave the pueblo. The advent of the *Kateinas* is accompanied by a personation of the sun, their leader, just as on the departure of the personated dead from the village the sun accompanies them to his western home.

The representation of the arrival and departure of the sun and his followers occurs annually in February and July, the former naturally beginning before sunrise, the latter at sunset. In the celebration of the arrival of the Sun god¹ leading the clan ancients, or *Kateinas*, two men retire, early in the morning before sunrise, to a shrine situated east of the town at the head of the trail, to dress in an appropriate manner. One of these (pl. 7) arrays himself to represent the sun (the horned serpent symbolism is absent), while the other serves as his guide, which is practically necessary on account of the size of the mask which his companion wears. These two men time their entrance into the pueblo in such a way as to enter it when the sun rises. They proceed in turn to all *kiwas* or sacred rooms and the houses of the foremost clans. The man personating the sun (pl. 7) carries in one hand a bundle of sprouting beans and

¹ Sky-God personations in Hopi Worship, *Journ. Amer. Folk Lore*, vol. 15, 1902. This article is limited to personations by men, whereas the present supplements it with representations by serpent effigies.



PLATE 7. THE SUN GOD OF THE KATCINAS.

- a*, Personation of the returning Sun god of the Katcinas.
b, Woman standing in doorway of home blessed by departing Sun.
c, Shell tinklers on leggings of Sun god.
ch, Ceremonial blanket.
ck, Crook, symbol of the offering to the Sun god.
e, Sprouting beans and vines, symbols of fructification.
f, Feather.
fs, Fox skin.
g, Ceremonial kilt.
hs, Stained red horsehair, symbol of sun's rays.
k, Embroidered edge of ceremonial kilt showing rain cloud and falling rain symbols.
l, Ladder.
m, Wall of house.
n, Stone stairs to upper rooms.
o, Star symbol.
p, Symbol characteristic of Sun's disk.
s, Eagle beak characteristic of Sun's disk.
sf, Staff with symbols of old man, Sun.
tf, Eagle feathers.



THE SUN GOD OF THE KATCINAS.

corn, and in the other a badge of his office. He performs the following rites at each house: Approaching the doorway, he is met by the oldest woman in the house, who throws a pinch of sacred meal on him, uttering a prayer for desired benefits. The personator in response makes six silent bows, turning first to the rising sun and then to the woman, to whom he repeats the same, after which he hands to her several kernels of sprouting beans as a symbolic promise in answer to her prayer. He then makes with sacred meal four upright bands on the side of the doorway, after which he departs to repeat the same proceeding at the next house. This occurs at the door of every ancestral room throughout the pueblo and at all the kiva hatchways. Having done this he departs, and in time there enters the pueblo from the east a line of masked men representing the masked clan ancients or *Katcinas*, who perform an elaborate rhythmic dance. These clan ancients, led by the Sun god, are supposed to have now returned and remain in the neighborhood until July, when they depart, at which time an event called the farewell dance¹ is celebrated.

The celebration of the advent of the Sky god followed by *Katcinas* at the pueblo *Sichomovi* differs somewhat from that at *Walpi* above described, mainly because this pueblo is of *Zuñi* derivation, being modified by personators of bird gods from the neighboring pueblo, *Walpi*. The leader is here called *Pauatiwa* (*Zuñi* name) and represents the Sky god; the *Katcinas* that follow are known by *Zuñi* names and wear masks decorated with *Zuñi* symbols.

The well-known Snake dance of the *Hopi*, in which rattlesnakes, called the elder brothers of the Snake fraternity, are introduced, is quite different from the horned serpent and *Katcina* worship described in the preceding paragraphs. Its present survival in the *Hopi* region and its known existence at *Keresan* pueblos, *Sia*² and *Acoma*, in historic times, we may ascribe to colonists whose ancestors came from the same area. It is preeminently the cult of a mountainous region, or a northern canyon culture, which spread to the south where it survived into the historic epoch.

The two cults—that of the horned serpent and that of the Snake dance—are regarded as radically different. In the latter the incarnation of the Sky god in various forms, as birds or horned serpents, plays no important rôle, while in the former there is abundant symbolism indicating sun worship, so called. The Snake dance of the *Hopi* is not primarily a Sky god cult, but rather a form of ancestor worship, in which the mythic Snake maid and the Snake youth figure prominently. These have been identified as representa-

¹A Few Summer Ceremonies at the Tusayan Pueblos. *Journ. Amer. Eth. and Arch.*, Vol. II, pp. 69–108, 1892.

²Tusayan Snake Ceremonies. 16th Rept. Bur. Amer. Eth., p. 309, 1897.

tives of the Earth being, or Corn maid, and the Sky god, but the conception they express is radically different from what we find in the horned serpent cultus. In the Snake dance of the Hopi we have a family ceremony in which the reptiles as elder brothers are gathered from the fields to receive the prayers of their living descendants. They are prayed to as the offspring of ancestral beings, and are supposed to have more power, in influencing the gods who cause the crops to germinate and mature, than the living or human descendants of the same parents. Throughout the legend that explains the Snake dance both sky (sun) and earth play their parts; the former guides the Snake youth through the underworld, and over the sky; the latter is his mentor, the Spider woman.

The prayers at the time of the Snake dance always present the desire of the Hopis for rain to water their farms that corn may grow and yield abundant harvests. Nowhere throughout the rite do we find any idols of these two culture ancestors, but they are represented by a boy and girl in the dramatization of the Snake myth, as recorded in my account of the Snake ceremonies at Walpi.¹ Unlike the *Katecinas*, the participants do not wear masks and no representative of the Sky god leads them into the village.

Nowhere in the Hopi ritual do we find more instructive examples of solar and sky worship than in the so-called Flute dance,² which has been modified by elements of the Snake dance. It would be germane to this discussion to indicate the points of relation between the myths and rites of the Flute and Snake priests, but it would take one too far from the immediate subject in hand. The objective symbolism dealing with sky worship found on one of the altars of the Oraibi Flute festival is worthy of analysis.

The most important idol of one of the Oraibi Flute altars (pl. 8) is identified as the "Heart of the Sky," another name for the sky power. This idol bears a horn on the head resembling that appendage of the horned serpent effigies. Its lower limbs are decorated with zigzag figures that symbolize the lightning, and there are other symbols on this idol that suggest the Sky god. On the sides of this image are idols of the Flute youth and the Flute maid, to which the prayers of the Flute priests for rain and the fertilization of the farms for good harvest are especially directed. The symbol of the sun is worn on the back of a priest in their march (pl. 9) from the Sun spring to the pueblos on the last day³ of the Flute festival. In the myth of the Flute fraternity there are constant references to Sky and Earth god worship in the underworld, which are

¹ Snake Ceremonials at Walpi. Journ. Amer. Ethnol. and Archaeol. Col. IV, 1894.

² The Walpi Flute Observance. A Study of Primitive Dramatization. Journ. Amer. Folk Lore, Vol. VII, No. 21, 1894. The Oraibi Flute Altar. Journ. Amer. Folk Lore, Vol. VIII, No. 31. The Miconinovi Flute Altar, Journ. Amer. Folk Lore Vol. IX, No. 35, 1896.

³ Tusayan Snake and Flute Ceremonies. 19th Rept. Bur. Amer. Eth. 1901.

rudely dramatized in the ceremonies, showing how important these nature powers are regarded. Although sky worship related to that of the horned serpent of the Patki clans appears in the Flute rite, mythologically and ceremonially, the Flute legend and rite resemble those of the Snake dance. These likenesses can be explained by legends that the Flute clans formerly lived with the Patki people and have mutually modified each other. It is instructive to note also that the Flute, like the Snake rite and that of the horned serpent, occurs in midsummer or near the summer solstice, which is a critical epoch in the calendar of all agricultural people.

There occur among the Hopi a few rites about sand pictures of the Sun made on the floors of the kivas. One of the most typical examples of these minor rites occurs in the pueblo Oraibi preceding the return of the Katcinas, or a few days before the advent of the personation of the Sky god which has been described above. The sand painting, a foot and a half in diameter, bounded by four concentric circles of different colored sand, incloses a central area in which is represented the prescribed symbol of the sun. On quadrants of this circular figure there are representations in sand of four arrowheads, each of the color corresponding to the direction of its quadrant, and also four parallel lines, symbols of feathers. After certain preliminary rites, as exchange of terms of relationship, ceremonial smoking and prayers, songs are sung during which the chief takes a flat bowl, perforated with small holes, and sprinkles the sand picture several times with "medicine," at the same time invoking the gods of the four cardinal points.

In the course of this rite a quartz crystal is deposited on the face of the sun represented in the sand picture, but before it is placed there one of the priests, mounting the ladder and standing at the entrance to the kiva, reflects a ray of sunlight upon the picture.

The object of the rite is to convey their desires to the Sky god by sympathetic magic. Instead of asking the Sun god to send the rain, the priests show by action and gestures what is desired, the reflected ray of light from the sun being the induction of the power of the Sky god into his image.

This throwing of the sun's ray into a medicine bowl by reflection from a rock crystal is repeated in other rites in the same way as mentioned above, even when there is no sand picture of the sun. For instance, it occurs in the rite around what is called the six-directions altar, constructed in the following way: After having spread out on the floor a layer of valley sand, the priest makes six converging lines of sacred meal, one of which represents the north, another the west, another the south, another the east, and two others the above and below. At the point of convergence of these lines is placed

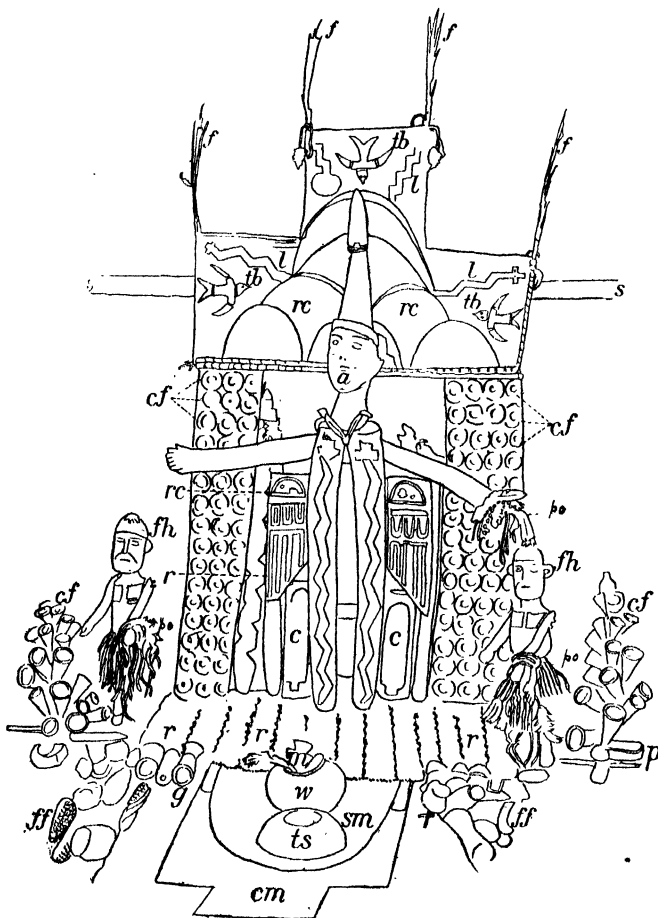


PLATE 8. ALTAR OF THE FLUTE (DRAB) AT ORAIBI.

a, Heart of the Sky; anthropomorphic form of Horned Serpent; the zigzag symbols represent lightning; cephalic horn; wings; *rc*; prayer emblem, *po*, breath feathers carried in left or ceremonial hand.

c, Corn slabs of wood.

cf, Corn flowers.

cm, Corn mosaic, made of kernels of corn.

f, Heads of grass seeds.

fh, Idol of Flute hero, offerings in left or ceremonial hand.

g, Unknown objects.

l, Lightning symbol.

m, Symbolic corn plant.

p, Wooden base of symbolic corn plant.

po, Prayer feathers.

r, Falling rain.

s, Wooden rod supporting altar framework.

sm, Sand mosaic.

tb, Bird.

ts, Mound of sand to support badge of flute chief, temporarily removed.

w, Medicine vaso.



ALTAR OF THE FLUTE (DRAB) AT ORAIBI.

an earthenware bowl containing the "medicine." At the extremity of each line is an ear of corn of the color corresponding to the direction indicated by these lines; yellow corn for the north, blue or green corn for the west, red corn for the south, white corn for the east, speckled corn for the above, and black corn for the below. On each one of these ears of corn is laid a stone and a drop of honey. The object of the stone is to indicate that the worshipers wish the corn to be hard; that of the honey is to ask for sweet corn of the different colors.

In the course of the songs and prayers about the six-directions altar, petitions are made for abundance of maize, during which, in sequence, each ear is solemnly raised by the priest, dipped in the medicine, and the adhering drops shaken off in the direction indicated by the color of the corn, the stones being left in the medicine. At the conclusion of this rite the priest takes a quartz crystal, mounts to the entrance of the kiva in the roof, and reflects a ray of sunlight into the liquid contained in the medicine bowl.

There are here three different kinds of sun worship due to the northern, eastern, and southern components of the Hopi ritual, but what is said here must be very general in nature. The northern component is, of course, the cult with the living snakes or the famous Snake dance. There are no masked dancers in the Snake dance, no uprights to the altars unless the painted slat called the "butterfly tablet" be so regarded; no anthropomorphic idols except the two on the Snake altar at Oraibi; no prominent plumed serpent or Sky god worship. The cultus hero and heroine are personated by a boy and a girl. This cult is simple as compared with those from East and South.

The cults of eastern and southern provenance have more in common; the Katcinas, derived from the East and South, personify clan ancestors led by the Sky god, both personated by masked men. The Katcinas have elaborate altars with idols, as in their equinoxial and solstitial worship the Patski people have elaborate effigies of the horned serpent, corn maids, germ gods, and the like. There are many minor differences, as presence of clowns, multitude of prayer sticks and the like, but cults of eastern and southern derivation are evidently higher in development, more varied or more differentiated, showing that the Snake dance bears every evidence of being not only a simpler form of worship, but also distinct in its geographical origin from the others, as the Hopi claim. We may call it the cult of the Teamahias or ancient people of the San Juan ruins, strongly represented in pueblos of ancient and surviving in pueblos of modern Keresan stock.

In many of the public sacred dances in Hopiland there appears among the participants a personage who bears on his back a shield.

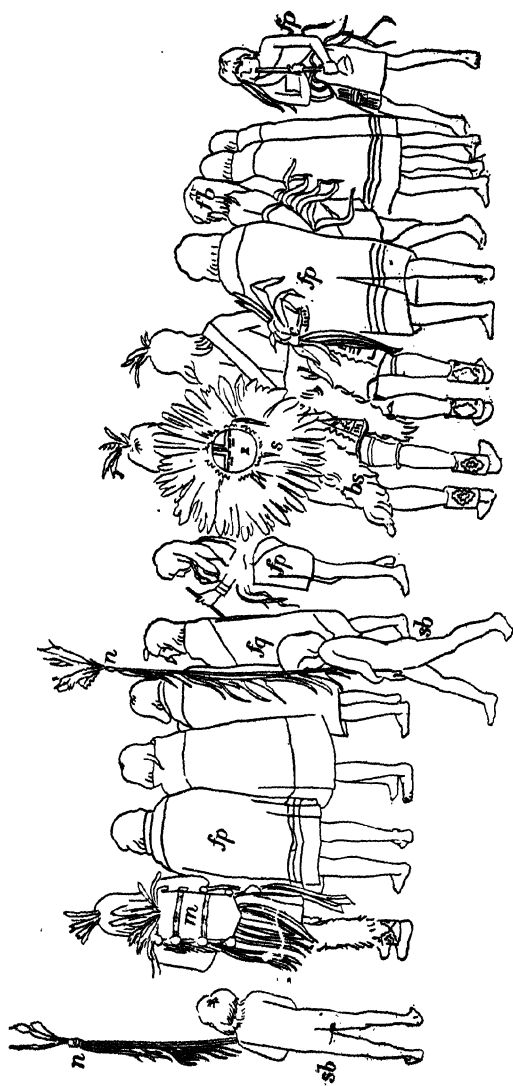
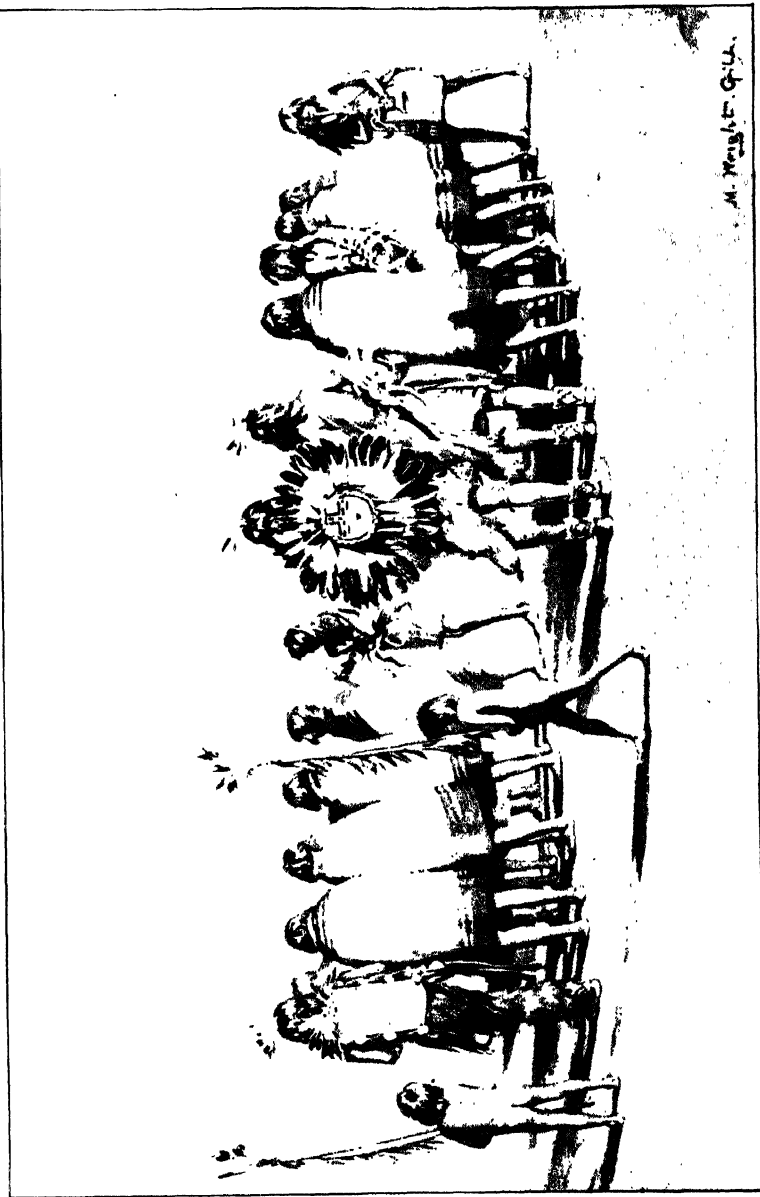


PLATE 9. MARCH OF THE FLUTE PRIESTS FROM SUN SPRING TO WALPI.

ba, Flute priest with sun symbol on his back.
c, Corn pants.
fb, Flute youth.
fp, Flute priests.
fg, Flute maid.
m, Moisture tablet symbolic of the earth fertilized.
n, Standard of the Flute Society.
s, Sun emblem.
sb, Standard bearers.



MARCH OF THE FLUTE PRIESTS FROM SUN SPRING TO WALPI.

on which is depicted the sun emblem (fig. 1 and pl. 9). This appears in certain dances that are worn down to their essential features, having lost in the course of time subsidiary rites which legends declare formerly accompanied them. Take, for instance, the Buffalo dance. Buffalo hunting was common among some of the ancestors of clans that now live with the Hopi, but in the course of time these clans migrated into a region where the buffalo no longer ranged. Naturally, the buffalo cult declined and their great ceremony assumed a contracted form as compared with the original. It has, in fact, be-

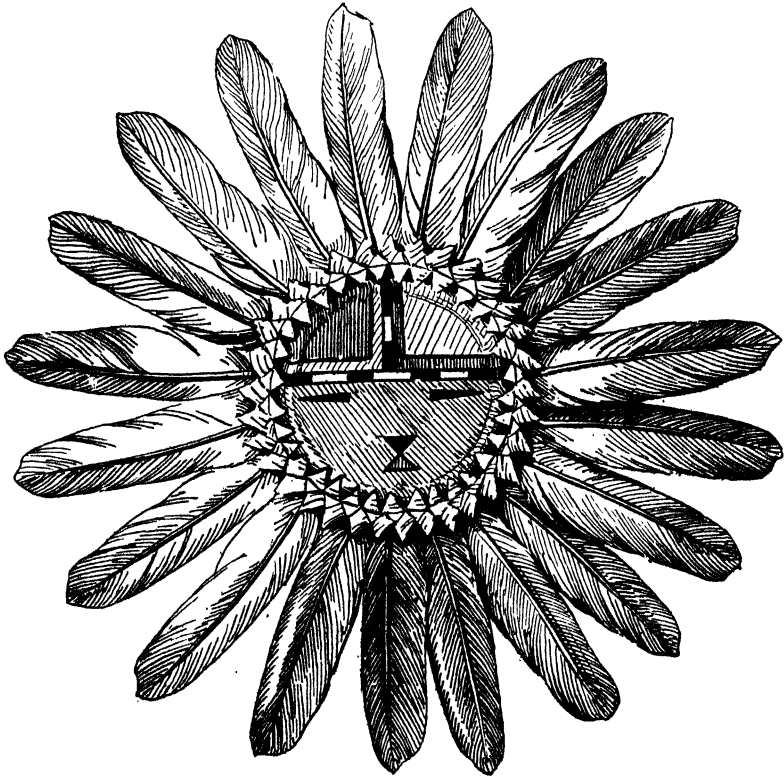


FIG. 1.—SUN EMBLEM (horsehair stained red omitted).

come a spectacular dance of one day's duration, in which appear a girl called the Buffalo Maid and a boy called the Buffalo Youth (pl. 10), the cultus heroine and hero of the Buffalo cult. On the back of the Buffalo Maid is an elaborately made symbol of the sun, while the youth carries a zigzag stick representing the lightning. The signification of these two symbols is apparent; the Buffalo Maid is the daughter of the Sun or the Sky god, and the Buffalo Youth the agent who wields the lightning that fertilizes the earth to produce buffaloes, a modified form of the elaborate drama already described.



PLATE 10. BUFFALO YOUTH AND MAID.

bh, Cap made of buffalo skin.

bs, Skin, symbol of buffalo disguise, formerly a buffalo skin.

cb, Ceremonial blanket, embroidered.

dk, Ceremonial dance kilt with embroidered rain clouds and falling rain.

h, Horns of buffalo.

k, Ceremonial kilt.

l, Stick symbolically representing lightning.

m, Moccasins with fringe.

po, Prayer feathers.

rt, Rat'tle.

s, Symbol of the sun.

sl, Sun ladder, prayer stick.



BUFFALO YOUTH AND MAID.

One more fact might be mentioned in regard to this abbreviated Buffalo dance, namely, that the prayer offering (pl. 11) made after the dance at the Sun shrine has a very unusual form. It is, in fact, a miniature notched ladder about 6 inches long, adorned with feathers, in imitation of the prayer stick which is placed in the Sun shrine at the east. The recognized object of this strange offering is to aid, by sympathetic magic, the Sky god in rising, as recounted in an elaborate legend to which the legendists of certain clans refer when asked to account for this form of sun worship among the Hopi.

Studies of the idols of the great serpent, taken in connection with Hopi myths and modern ceremonial survivals and symbolism, lead to the conclusion that the great serpent effigy or idol on Hopi altars is the personation of the power we commonly call the Sky god. This power, or the fructifying principle of nature, becomes manifest to man as the lightning, but is visible also as the sun, which has its appropriate symbol and personation. Hence, Sun worship and great serpent worship are indissolubly connected and by some are thought to be identical. They are not the same, but regarded as different, being directed to attributes of the same supernatural being and therefore aspects of the same worship. This power is called by as many names as the personators assume.

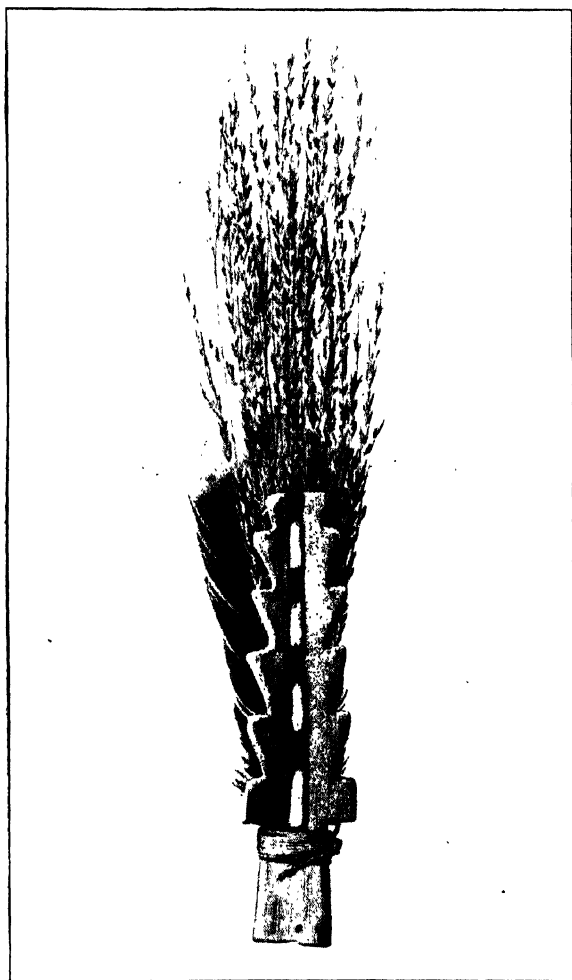
When we analyze the meaning of the great serpent represented by God B of the Maya codices or horned serpent figures on shell and other objects from the Mound Builders¹ indicating a similar symbolism, we find evidences of the same conception of a great power sometimes called the Sky god, the great male power that creates, among other things, life and light.

The worship of sun or sky is pronounced in certain individual and secular customs of these people. If he visits any of the dwellings where there is a newly born baby a few days old, the observer will notice on the wall of the room near the fireplace a number of parallel scratches a few inches long made by the thumb-nail. Every day after birth the mother of the baby makes an additional scratch, until they are 20 in number. On the evening of this day begins the rite of consecrating the baby to the sun and giving him a name. In order to see this rite one should spend the night in the room, where he is always welcome, as many of the preliminary events occur before sunrise. About 4 o'clock in the morning the grandmother, or the oldest woman member of the family, prepares for the event. The room is carefully swept, the baby washed, its face covered with sacred meal, an ear of corn tied to its breast. This ear of corn is the symbolic mother of the child, and is carefully preserved through its life. Shortly before sunrise the father seats himself on the east side of the roof, completely muffled up in a blanket with only

¹ Also the great serpent mound of Ohio.

his face showing. He carefully watches the point of sunrise, and as soon as he sees the light of the rising sun he gives the signal that the time has come for the dedication of the child. There then emerges from the room a procession, led by the mother of the child, and followed by the grandmother, or oldest woman of the clan, who carries the baby strapped to one of the primitive cradles characteristic of these people. The mother traces along the roof a line of sacred meal extending from the entrance of the room to the place where the father is seated. The grandmother follows her daughter holding the cradle in such a way that the head of the child will not diverge on one side or the other from this line, the purpose being that the life of the child may not be crooked, but morally follow the symbolic straight line drawn by the mother. The two women are attended by the other relatives of the family, mostly girls and women. As the head of the procession approaches the father, which is so timed that the sun has just appeared above the horizon, the grandmother holds the baby up to the sun, and the mother says a short prayer, dedicating her child to the being she regards, as do all pious Hopi, the father of all life, at the same time adding the name which she desires her child should bear. At the conclusion of this simple ceremony all return to the household, where a feast has been provided. The baby being the honored person, is placed at the head of the two lines around the bowls of food, but before anyone begins to eat the mother takes in her hand a pinch of every kind of food and throws it in the fire, with a prayer to the gods of the hearth. She then returns to the food bowls, takes a second pinch of all the different kinds of food provided in the feast, and carries it to the baby, placing it in its mouth. The signal is then given and all those present, augmented by many others who perhaps were led to the household for that purpose, begin the feast.

This dedication of the baby to the sun is the first of several rites which occur in the individual life of every Hopi. When the child arrives at years of discretion it is customary to impart to him the knowledge of his relationship to supernatural beings. In other words, up to that time children have been taught to believe that the personations of *Kateinas* are gods that from time to time perform their elaborate dramatization in ceremonial dances. It is deemed necessary to impart to youths the fact that the priests who personate these beings are their own relatives, but this knowledge must be obtained by a flogging, or by personal suffering. The rite of flogging the children is complicated, and has been elsewhere described, but it suffices our purpose here to mention the fact that the person who flogs the children represents the Sun god. The whole ceremony is explained by an ancient legend which is somewhat as follows, omitting details not germane to our subject.



SUN LADDER PRAYER STICK CARRIED BY THE BUFFALO MAID AT HANO.

In very old times, the legend states, before the seeds of corn and other food which form the diet of the Hopi were brought to mankind, thereby changing their cultural condition, the announcement of this gift was made to a gathering of people who sat around a large sacred stone bemoaning their lot. A voice issuing from beneath the stone, called to the bravest of them to go down into the bowels of the earth to meet the God of Germs. No one of their number dared to accept this invitation save a young man not yet of high standing in the priesthood. He replied to the voice, "What shall I do to enter the underworld?" and the voice replied, "Put your hand on the rock before you." The boy immediately did this and a cleft appeared, widening into a passageway through which he descended.

He passed into the underworld and there entered a beautiful room adorned with sea shells, turquoises, and other objects dear to the Hopi heart. In the middle of the room was the god resplendent in his costuming, wearing about his loins a girdle made of red horse-hair, holding in one hand the shield of the sun and in the other a whip made of the yucca. As the boy approached this being he was greeted with the words "You are welcome here, but you must endure much suffering before you depart. If you are brave of heart you will carry back to your people gifts of great value." Without hesitation the boy advanced and said, "I am ready for any ordeal." Immediately after, the god raised his whip, which, like a stroke of lightning, descended on the bare back of the youth. For some time this went on until the boy was almost exhausted with loss of blood, but he still kept his brave heart, and at the close the gods presented him with a prayer plume with the words "Annually you must plant this stick in my shrine in the upper world and I will bring you all the gifts of nature as a reward. You must perform this initiation ceremony with the youths of age in the village, dressed in the same way as the sun, and singing the same songs which you have here heard. As a proof that I will aid you, I give you here a bundle of seeds which you shall plant yearly. Put your hand upon the rock above you." As he obeyed this command, the rock opened a passageway and the boy passed out to his sorrowing friends. The passageway then closed, and the boy put **his** hand again on the rock, but it did not open, although the impression of that hand is still pointed out on a rock in the valley below. When he emerged from the underworld, he told the assembled men nothing of his adventure other than that every year the boys and girls of a certain age should gather together in the kivas and he would perform the mysteries of the initiation through which he had already passed in the underworld. "And that is why," added the narrator, "every year in February the personators of the Sun god flog our children

that they may be brave of heart, and that the Sun god in turn may bring his blessings of abundant crops and fertilizing rains."

The last ceremony in the individual life of a Hopi is also connected with the worship of the sky power, or his personation, the sun god. After death the deceased is mourned for a limited time by the relatives, during which there is placed over his face a wad of cotton batting called a mask, in which are pierced two openings for his eyes, and he is addressed as follows: "You have become a Katcina. Aid us in bringing the rain, and intercede with the gods to fertilize our farms." It will be noted that the dead is addressed by the same name as that given to the ancestral personations, which play such a prominent rôle in the worship and ceremonial dances of the Hopi. After other rites, which need not be mentioned at this time, the corpse is wrapped in blankets, in a contracted position, the knees brought to the chin; carried down the mesa by the oldest man of his clan, accompanied only by one or two male relatives, and deposited in a sitting posture in a rudely made grave among the rocks of the foothills. The corpse is placed looking toward the east, and for four days bowls of food and prayer offerings are placed over the grave, but the place of burial is known only to the intimate relations. It is the belief of the Hopi that the spirit of the dead remains in the grave four days, and that the "breath body" of the food placed there is for the consumption of the spirit, or "breath body" of the dead; but at sunrise on the fourth day it is thought to emerge from the grave, and is supposed to follow the sun in its course to his house in the west, which is situated beyond the horizon, indicated by a notch near the San Francisco Mountains, and on to the abode of the dead. The object of placing the dead facing the east is that he may see the sun when it rises and be able to emerge from the grave in time for the journey. Under guidance of the sun, the "breath body" enters the underworld, and is received by the ghostly inhabitants which people it, for this is the abode of the dead, and the Sky god is a ruler of that world, in the Hopi conception. It may be said incidentally that the occupations which the apotheosized pursue are practically identical, in their conception, with those of the quick in the upper world. They not only perform the same secular work as on earth, but also engage simultaneously in similar ceremonies, and at times communicate with them through a hole (*sipapu*) in the floor of the kiva, returning from time to time as already described in those dramatic dances known as the *Katcinas*. It will thus be seen that in individual rites from birth to death the worship of the Sky god, in the form of the Sun god, is always present in the Hopi mind, as well as in their great dramatic ceremonies.

A CONSTITUTIONAL LEAGUE OF PEACE IN THE STONE AGE OF AMERICA.

THE LEAGUE OF THE IROQUOIS AND ITS CONSTITUTION.

By. J. N. B. HEWITT.
Bureau of American Ethnology.

In the Stone Age of America the Mohawk, the Onondaga, the Oneida, the Cayuga, and the Seneca, five Iroquoian tribes dwelling in the central and the eastern regions of what is to-day the State of New York, established a tribal federation or league, with a carefully prepared constitution, based on peace, righteousness, justice, and power. These five Iroquois tribes spoke dialects of the Iroquoian stock of languages, which is one of about 50 spoken north of Mexico.

After more than four years of a world war, characterized by such merciless slaughter of men, women, and children, by such titanic mobilization of men and weapons of destruction, and by such hideous brutality, that no past age of savagery has equaled them, the peoples of the earth are now striving to form a league of nations for the expressed purpose of abolishing the causes of war and to establish a lasting peace among all men.

So, of more than passing interest is the fact that in the sixteenth century, on the North American Continent, there was formed a permanent league of five tribes of Indians for the purpose of stopping for all time the shedding of human blood by violence and of establishing lasting peace among all known men by means of a constitutional form of government based on peace, justice, righteousness, and power, or authority.

Its founders did not limit the scope of this confederation to the five Iroquoian tribes mentioned above, but they proposed for themselves and their posterity the greater task of gradually bringing under this form of government all the known tribes of men, not as subject peoples but as confederates.

The proposal to include all the tribes of men in such a league of comity and peace is the more remarkable in view of the fact that that was an age of fierce tribalism, whose creed was that no person had any rights of life or property outside of the tribe to whose

jurisdiction he or she belonged, and that every person when beyond the limits of his or her tribe's protection was an outlaw, and common game for the few who still indulged in the horrid appetite of cannibalism. So that the doctrine of the founders of the league that all persons by adopting their formulæ could forego the shedding of human blood and become related as "fathers" and "mothers" and "sons" and "daughters," in the terms of Iroquoian kinship and affinity, was revolutionary and most disturbing from the viewpoint of this intense tribalism. It was the central teaching of Deganawida, the great statesman and lawgiver of the Iroquois people in the sixteenth century, that out of the union of a common motherhood and a common fatherhood arise the daughtership of all women and the sonship of all men, and the rich fellowship of all mankind.

The establishment of the league of the five Iroquois tribes in the closing decades of the sixteenth century was in large measure not only a drastic reformation but also an experiment. Avowedly it was designed as an institution for the extension and preservation of peace and equity and righteousness among all men; and it made a fundamental departure from the practice of the past in completely excluding in so far as terms go the military power from participation in the conduct of purely civil affairs.

When using the terms war and warfare, it must be remembered that while they denoted defensive, apprehensive, and offensive strife, and the mood and the means (the weapons belonging thereto), they did not imply the war and warfare waged by a military State, a body of soldiers, drilled and regimented and organized independently of the civil body. There were, strictly speaking, no armies among tribal men; only the beginnings, the more or less developed germs of these things. There were, indeed, groups of fighters who were regimented and organized, not in a practical or rational manner and mood, but in accordance with mythical and sociological conceptions and predispositions, and strictly with relation to their kinship status, individually and severally, in the tribal organization to which they belonged. For every tribe, great or small, or group of tribes, was, exclusive of the women and the children, an inchoate, undifferentiate army, a group of instant or else actual fighters.

For like reasons there was no State religion, where all forms and moods of it were tolerated and practised.

At the period of the formation of the league and for at least 75 years afterwards these five tribes, thus united, were surrounded by a number of powerful and hostile tribes, nearly all of which were cognate with them in speech. On the St. Lawrence River, approximately on the present sites of the cities, Montreal and Quebec, dwelt two strong Huron tribes. On the upper Ottawa River were the Algonquin and their congeners. Around Lake Simcoe were two

more powerful Huron tribes, to which the two mentioned above as living on the St. Lawrence River migrated about the beginning of the seventeenth century, and formed an alliance with them. These are the four Huron tribes mentioned in the Jesuit Relations. Southward from the Huron tribes, and in the peninsula lying westward from Niagara River and northward from Lake Erie and extending eastward over Niagara River to the watershed of the Genesee River in New York State, were situated the numerous towns of the powerful "neuter nation," also of cognate speech. South and southeastward of Lake Erie dwelt the warlike Erie, who also were of cognate speech with the Iroquois tribes; and still farther eastward were the little known Black Minqua also of cognate language. In the upper Susquehanna river valley, especially in the Wyoming valley, lived the noted Massawomeke also of cognate speech. On the lower Susquehanna dwelt the fiercely warlike Conestoga. On the Delaware river and its affluents dwelt the Lanape or Delaware tribes who spoke Algonquian dialects. Eastward, along and beyond the Hudson River dwelt the Mohegan and their cognates who also spoke Algonquian dialects. Such summarily was the tribal environment of the five Iroquois tribes at the era of the institution of their league or confederation. Tradition is silent as to any extensive warfare with these surrounding tribes anterior to the founding of the league.

History records the use of two fundamentally distinct methods of grouping peoples by means of institutional bonds. The grouping of men in this manner has been aptly termed regimentation. The two systems mentioned are the tribal system of regimentation and the national system of regimentation. In the first, men are regimented or organized on the basis of kinship and affinity, real or as a legal fiction, and in the second, men are regimented or organized in institutional units on the basis of territory. But history records transitional forms of organization, and the most important of these is the feudal, for both methods mentioned above are found in feudal society, showing transition from tribal to national society and government.

Now, the tribes of the Iroquoian stock of languages are regimented or organized on the basis of kinship and affinity, real or as a legal fiction, and they trace descent or lineage of blood only through the mother.

To grasp fully and to comprehend clearly the structure and the workings of the great institution which is called the league or confederation of the Five Nations, one must have a summary but clear knowledge of the several constituent units which in the last analysis have voice and place in its structure and workings.

In brief, these are the ohwachira (=the uterine family), of which one or more constitutes a clan; the clan, of which one or more may constitute a sisterhood, or, as it is usually called, a phratry of clans; the sisterhood or phratry of clans, of which only two constitute a tribe in Iroquois social organization; the tribe, of which two or three constitute a sisterhood or phratry of tribes; and finally the league or confederation which is composed of just two sisterhoods or phratries of tribes.

The common noun ohwachira (as pronounced by the Mohawk and other *r*-sounding dialects) or ohwachia (as uttered by the Onondaga and other *r*-less dialects) signifies a group of male and female uterine kin, real, or such by legal fiction. It includes all the male and the female progeny of a woman, and also the progeny of a woman and of all her female descendants, tracing descent of blood in the female line and of such other persons as may have been adopted into it. In so far as known the ohwachira, unlike the clan, does not bear the designative name of a tutelary or other protecting genius, or "totem" as it is commonly but loosely called when applied to a clan; and yet it is commonly known that the influential matron of an ohwachira usually bears the reputation of being deft in the peculiar arts of the sorceress, each of which being the potence or orenda of some tutelary.

The matron of an ohwachira is usually, not always, the oldest woman in it. But, by becoming incapacitated by age or other infirmity to manage the affairs of an ohwachira as its moderator, she may ask permission to resign so that a much younger woman of recognized ability and industry and integrity of character may be nominated and installed to preside over the ohwachira in her stead.

Naturally, the ohwachira had as many firesides as it had women who were married. Each married woman of an ohwachira used one side of one of the fires at the center of the lodge. The Iroquoian lodge was extended lengthwise to accommodate those who dwelt in it, and the fires were kindled along the center from place to place.

The members of an ohwachira have (1) the right to the name of the clan of which that ohwachira is a constituent unit; (2) the right of inheriting property from deceased members of it; (3) the right to take a part in the councils of the ohwachira; (4) the right to adopt an alien through the advice of the presiding matron of it.

In the present organization of the league, only certain ohwachira have inherited chiefship titles, the principal and the vice-chief, and, consequently, the right to name any of its members to fill these offices; after the formation of the league these nominees had to be installed by federal officers, but previously by tribal officers. Strictly speaking, these titles of chiefship belong to the mothers in the ohwachira, over which the presiding matron held a trusteeship.

Rarely, the offspring of an adopted alien came to constitute an ohwachira having chiefship titles; but this was first only a trusteeship of the titles, which belonged to an extinct, moribund, or outlawed, ohwachira. A basic rule of the constitution of the league of the Iroquois provides in the case of the extinction of an ohwachira owning chiefship titles, that for the preservation of this title, it shall be placed in trust with a sister ohwachira of the same clan, if such there be, during the pleasure of the council of the league. This was a most important law in view of the fact that no new federal titles were instituted after the death of Deganawida, the prophet statesman of the Iroquois.

The women of marriageable age and the mothers in the ohwachira had the right to hold councils; especially, such as those at which candidates for chief and vice-chief might be nominated by the mothers alone. At such councils these women had the right to formulate some proposition for discussion by the tribal council; it might be done in conjunction with other ohwachira. (This is, in embryo at least, the modern so-called right of initiative.) In like manner, a proposition might be made to the tribal council to submit to the suffrages of all the people, including infants (the mothers casting their votes), any question which might be occupying the attention of the council or the people. (This is, in embryo at least, the modern so-called right of referendum.)

It is the right of the matron of the ohwachira whose chief wanders away from the path of rectitude to take the initial step in his deposition for cause—first, by going in person to him and warning him to reform and to return to the path of right and duty; if he fails to heed this warning she seeks out her brother or eldest son, as a representative of the men of her ohwachira, and together they go to give the erring chief the second warning. If still he persists in the neglect of duty and in doing wrong, the matron then goes to the chief warrior of the ohwachira, and then these three together go to him and merely inform him that he must appear on a given day at the tribal council. There the chief warrior asks him categorically whether he will or will not conform to the expressed wish of his ohwachira. If he refuse to reform he is at once deposed, the chief warrior figuratively removing from his head the "symbolic horns" (i. e., receiving back the wampum strings which are the certificate of his official title) of his title and handing them to the matron. (This is, in brief, the recall of modern times.)

In the structure of the league several ohwachira, some having a chiefship title, are incorporated to form one clan, so that this clan is represented in the tribal or the federal council by two or more chieftains. It so happens that the Mohawk and the Oneida tribes have only three clans each; but each of these clans has three oh-

wachira which have a principal chief and a vice-chief, respectively; and so these two tribes are represented in council, when all are present, by nine chiefs and nine vice-chiefs or messengers, the latter of course have no voice in the deliberations except in case the chief be, for some reason, unable to attend a council when he may deputize for such council his messenger to act for him. In the nature of things, every ohwachira of the Iroquoian tribes formerly possessed and worshiped, in addition to those owned by individuals, one or more tutelary deities or genii called ochinagenda, in modern usage, but formerly named oiaron (or oyaron) with a larger meaning, which customarily were in the secret custodianship or trusteeship of certain wise women who were usually named physicians, but who were in fact also so-called witches.

The ohwachira or uterine family was the primary unit of the social organization of all Iroquoian tribes. It must not be overlooked that the members of an ohwachira could not marry one another, nor could the members of a clan, composed of one, two, or more, such ohwachira, which by thus uniting to form a single organic unit become sisters, or sister ohwachira, and the members of the unit so formed become exogamous with relation to one another. The union of two or more organic units naturally produced an organization of a higher order and an enlargement and a multiplication of rights, obligations and privileges.

It will be needful to keep in mind the fact that the women of an ohwachira who elected to marry had to do so only with men from ohwachira which had a cousin relationship to their own, for they must not commit incest by marrying men from their own ohwachira or men from a sister ohwachira. Thus, every ohwachira which had women who were married was interrelated with many cousin streams of blood, and it is these outside ties which bound together the various blood streams. Iroquoian society is then held together by the bonds of affinity, while the tracing of the descent of blood through the women preserved its purity and insured its continuity.

When an ohwachira became an integral part of a clan—a higher unit—it necessarily delegated some of its self-government to this higher unit in such wise as to make this union of coordinate units more cohesive and interdependent. Thus the institution of every higher organic unit produced new privileges, duties, and rights, and the individual came under a more complex control and his welfare become more secure through tribunals exercising a greater number of delegated powers in wider jurisdiction.

Status in an Iroquoian tribe was secured only by being born into it, by virtue of birth in one of its uterine families or by adoption into it. But an alien could be and was adopted into citizenship in the clan and tribe only by being adopted into an ohwachira (uterine

family) of some clan. The ceremony of adoption was so potent that where two alien sisters were adopted, each into a clan which intermarried with the other, their children intermarried as coming from exogamous groups.

Whatever land was held by the ohwachira for cultivation and on which fuel and berries and nuts and roots and bark and medicines and poisons were procured, belonged exclusively to the women of the ohwachira.

Ordinarily, the members of an ohwachira were obligated to purchase the life of one of its members who had forfeited it by a homicide and to pay for the life of the victim as well.

It was seen that the earth produced things which were fixed in her breast; all the things that grow whether corn, beans, squashes, berries, or nuts, are nourished directly by the earth. In like manner it appeared that woman, the mother, was a producer, and nourished what she produced on her breast; hence, the woman and the earth are sisters. So the cultivation of the things that grow out of the earth is especially the duty and pleasure of woman. While the pursuit of game, and fish, and birds, and men who are not fixed in the earth was strictly within the prerogative of the men.

The ohwachira through its matron exercised the right to spare, or to take, if needs be, the life of prisoners of war in its behalf and offered to it for adoption. Such briefly is the ohwachira of Iroquoian social organization.

The Iroquoian clan is an intratribal exogamic body of uterine kin, real, or such by legal fiction, regimented for the purpose of securing and promoting their social and political welfare. The clan has a name, which serves as a class or preferably unit name for its members, and which is derived usually from some animal or bird or reptile belonging to the habitat of the ancestors of this body of kin, or to its customary tutelary genius. The lineal descent of blood, the inheritance of property, both personal and common, and the hereditary right of eligibility to public office and trust are traced in the clan through the female line attained through the action and interaction of its constitutive units—the ohwachira (the uterine families).

The Iroquoian clan is constituted organically of one or more ohwachira; its chief or chieftains came to it through its constituent ohwachira which may have possessed such officers. A large number of the characteristics of the ohwachira may be predicated of the clan, for the reason that the ohwachira gave up for administration to this larger grouping a number of their functions. So that a clear knowledge of the ohwachira is first needed to understand what a clan is.

The following summary of the characteristic rights and privileges of an Iroquoian clan may be enlightening: (1) The right to a distinctive name, which an invariable custom derives from some animal, bird, or reptile, characteristic of the habitat, which may have been regarded as a guardian genius or protecting deity. (2) Representation by one or more chiefs in the tribal council. (3) An equitable share in the communal property of the tribe. (4) The right and obligation to have its nominations for chief and subchief of the clan confirmed and installed by officers of the tribal council in earlier times, but since the institution of the league, by officers of the federal council. (5) The right to the protection of the tribe of which it is a constituent member. (6) The right of the titles of the chiefships and subchiefships hereditary in its ohwachira(s). (7) The right to certain songs, chants, dances, and religious observances. (8) The right of its men or women, or both together, to meet in council. (9) The right to the use of certain names of persons, which are given to its members. (10) The right to adopt aliens through the action of a constituent ohwachira. (11) The right of its members to a common burial ground. (12) The right of the mothers of constituent ohwachira(s), in which such official titles are inherent, to nominate candidates for chief and subchief; some clans have more than one of each class of chiefs. (13) The right of these same mothers to take the prescribed steps for impeaching and deposing their chiefs and subchiefs. (14) The right to share in the religious rites, ceremonies, and public festivals of the tribe.

The duties incidental to clan membership are the following: The obligation not to marry within the clan, formerly not even within the sisterhood or phratry of clans, to which the one in question belonged; the effect of membership in the sisterhood of clans was to make all men either mother's brothers or brothers, and all women mothers or sisters. (2) The joint obligation to purchase the life of a member of the clan which has been forfeited by homicide or the murder of a member of the tribe or of an allied tribe. (3) The duty and obligation to aid and to defend its members in supplying their wants, redressing their wrongs and injuries through diplomacy or by force of arms, and in avenging their death. (4) The joint obligation to replace with prisoners or other persons other members who have been lost or killed, belonging to any ohwachira of a clan to which they may be related as father's brothers or father's clansmen, the matron of such ohwachira having the right to ask that this obligation be fulfilled.

The clan name is not usually among the Iroquois the common designation of the animal or bird or reptile after which the clan may be called, but very commonly denotes some marked feature or characteristic or the favorite haunt of it, or it may be just a survival of an archaic name of it.

The number of clans in the different Iroquois tribes varies; the smallest number is three representative clans, found in the Mohawk and the Oneida, while the Seneca have nine and the Onondaga eight. There are also some clans which, having no chief titles, are seldom named in public.

In historical times, and in the past as far as tradition informs us, every clan belonged to a sisterhood or phratry of clans, and so was not directly a member of a tribe. In all Iroquois tribes two sisterhoods or phratries of clans are found, each forming one side of the dual tribal organization. One of the tribal sides represents the fatherhood or male principle and the other the motherhood or female principle among living things.

There are three native terms in the speech of the Iroquois which may be translated into English by the word chief or chieftain. These are in the third person and in the Mohawk dialect, as follows: *rakowā'né'*, *ră'sěñowā'ně'*, and *royā'ne'r*, each signifying "he (is) a chief." The first two are generic and so may be applied to civil or military chiefs, while the last is at present restricted to chieftains of the League, who represent their tribal constituencies both in the tribal council and in the federal council of the League, and also is applied to the women chieftainesses. The chief bearing the last name has a subchief or messenger, who is usually mentioned by the agnomen, "The Cane" or "The Ear," and who is symbolically represented as sitting on the roots of the Tree (the Chieftain) whose subchief he is. It is the duty of this subchief to see personally that the chief's orders in his official capacity are carried out—either in person or by the aid of the warriors or other members of the clan.

The first of these official names signifies "he great, noble, (is)," being derived from the stem meaning, "great, large, or noble." The second, meaning "his name great, noble, (is)," is derived from a compound stem composed of the noun "name" and the attributive qualifying stem just mentioned. The third term is notionally not connected with the two terms just mentioned. Its stem, *-yā'ne'r*, means "beneficent, bountiful, good, promotive of good or of welfare, (to be)." This stem is also the basis of the words for Law, the Commonwealth or the Institution of the League. Thus, in Iroquoian thinking a law, or the body of laws, is what brings to pass what is highestly or greatestly good. And so a federal chief could not engage in warfare while holding such a title.

Some biographic notice of at least four of the chief actors in the events leading up to the institution of the league may be of interest and be instructive. These four are Deganawida, Hiawatha, Djigonsasen, and Atotarho (Wathatotarho).

To begin with the first named. Deganawida was one of the world's wonder children. His conception, birth, and career are

largely idealized by tradition. Prophetic dreams and visions announced to his doubting grandmother his alleged divine origin and heavenly mission among men; prodigies attended his birth and childhood; he had power on earth and in heaven—that is to say, he knew and sought to do the will of the Master of Life, Te'haroⁿhywă'k'ho". His mother and grandmother were poor and despised and lived alone in a small lodge by themselves on the outskirts of the village to which they belonged, and so they had few, if any, visitors who might seek the daughter for a wife. But there came a day when the watchful mother became aware that her daughter would herself in due time give birth to a child, and bitterly did she reprove her for not marrying a man in the customary way, for now she was bringing scandal upon her mother and herself. The daughter, however, steadfastly denied that she had had commerce with any man at any time, but her mother doubted her and carried her reproof so far as to cause the daughter much bitterness of spirit, and she, therefore, spent much time in silently weeping, for she loved her mother and claimed that she did not know the cause of her pregnancy, and she was deeply grieved by her mother's chiding. It was then that the mother had a dream in which she was told by a divine messenger that she was doing her daughter great wrong in not believing her statement that she did not know the source of her condition; and she was further told that her daughter would bear a male child, whom they must call Deganawida, and that he would be indirectly the cause of ruin to their people.

The repentant mother upon awaking asked her daughter's forgiveness for the wrong she had done her in not believing her denials. They, however, decided to destroy the life of the child when it should be born because of the dream's declaration that he would grow up and be the source of evil to their people. So when the child was born they carried it to a neighboring stream of water, which was frozen over, and cutting a hole in the ice thrust the child into it to drown, and they returned to their lodge. But when they awoke in the morning they found the child unharmed and lying asleep between them. This attempt to rid themselves of this child was repeated twice more, but each time no harm came to the child, and then after consultation the two women decided that it was the will of the Master of Life that they should raise the child. They were most kind to him thereafter, and they gave him the name Deganawida, as the dream had directed the grandmother to do. He was reputed to have been one of seven brothers, but in regard to the father or fathers of the six younger brothers tradition is silent.

When he grew to man's estate he informed his mother and grandmother that he must leave them to perform a great work in lands

lying south of the great lake. He left them in a "white canoe," which perhaps was a canoe of white birch, which later tradition has carelessly confounded with the ice canoe (=ice block) in which the Iroquoian myth of the Beginnings says the Winter God goes from place to place and which by further corruption of the misconception in modern literature has become a "flint" or "stone" canoe.

Tradition ranks Deganawida with the demigods, because of the masterful *orenda* or magic power with which, it was alleged, he tirelessly overcame the obstacles and difficulties of his great task; because of the astuteness and the statesmanship he displayed in negotiation; and lastly, because of the courage and wisdom he showed in patiently directing the work of framing the laws and elucidating the fundamental principles on which they and the entire structure of the Iroquois league or confederation must rest, if these were to endure to secure the future welfare of their posterity. He was a prophet and statesman and lawmaker of the Stone Age of North America. Tradition ascribes his lineage to no tribe, lest his personality be limited thereby.

The traditions concerning the person who has become known as Hiawatha on close examination are found to describe two very different personages.

In one tradition Hiawatha when first seen by Deganawida was a cannibal and was actually engaged in bringing the carcass of a human being into his lodge, which he quickly proceeded to quarter and cook in a pot of water. He had been out hunting for human beings, and meeting this one had killed him for his larder.

Deganawida had previously heard of his cannibalistic habits from Djigonsasen, the chieftainess of the Neutral nation (or tribe), who was the first person to understand and to accept the radical program of Deganawida for stopping the shedding of human blood by violence and for the establishment of peace and equity and righteousness and power.

Unseen by Hiawatha, Deganawida, the tradition says, mounting to the top of the lodge watched Hiawatha at work; peering through the smoke hole from a point just over him, Deganawida saw what was being done by Hiawatha and, tradition says, caused him by mental suggestion to realize the horrible enormity of what he was then doing; so he mistook the face of Deganawida, reflected in the pot, for his own, and being struck with the great beauty of that face he contrasted it with the character of the work in which he was then engaged and exclaimed, tradition says: "That face and this kind of business do not agree"; and he then and there resolved to give up cannibalism for all time. He quickly arose and carried the pot out of the lodge and cast its contents away at some distance from the lodge.

Deganawida having descended from the top of the lodge went forward to meet his host. Because of his recent experience Hiawatha was very much pleased to have a guest who brought him the wonderful message of peace and righteousness and power. The result of this conference was the conversion of Hiawatha to the reform program of Deganawida and his agreement to aid in the work of bringing about the change in the attitude and relation of men one to another.

According to tradition, Deganawida gave him his name after his conversion, and Hiawatha became a loyal and enthusiastic disciple of Deganawida and gave up everything in order to devote all his energies and time to the work of establishing the projected league or confederation of peoples in accordance with the principles expounded by Deganawida. He indeed undertook several very important missions for his great teacher and acquitted himself with great credit.

The most effective and unscrupulous opposition the two reformers encountered in their work came from the noted Onondaga chief, Atotarho (Watatotarho), a wizard and sorcerer who was feared far and near, who, during the years in which the league was being brought into being, removed by secret means, it is said, the seven daughters (some versions say three) and then the wife of Hiawatha, his opponent.

No place is given by tradition as Hiawatha's birthplace, although some analysts declare that he was a half-brother of the fierce chieftain Atotarho (Watatotarho), of the Onondaga, his pitiless antagonist.

This tradition asserts that he lived among the Mohawk and married the daughter of a chief there and that he himself became a chief among these people. His name is still on the list of titles of federal Mohawk chiefs.

In the other version of the tradition of the founding of the league of the Iroquois Hiawatha is treated as the chief actor in the conception and establishment of this confederacy instead of the real founder, Deganawida. But from a careful survey of the narrative of events herein this version is found to be much less faithful to facts than the one first mentioned.

It appears that in this tradition the several missions upon which his mentor, Deganawida, sent him, were fused together in such wise as to make them merely a series of events or episodes in a single journey of Hiawatha, which he was alleged to have made in despair, going directly southward from the Onondaga council lodge; on this journey he was said to "have split the sky," meaning merely that he took a course directly south. Herein, too, he fled from Onondaga

because of vexation of spirit for the loss of his children by the will of the great sorcerer, Atotarho (Watatotarho).

The descriptive details are highly interesting to the antiquarian because they shed some faint light on the kind of pledge or vouch which was in use before wampum and wampum strings came into vogue for that purpose. On this journey some of the persons delegated to communicate with Hiawatha used for a pledge small shoots of the elderberry bush which were cut into short pieces, and from which the pith was removed, and these little cylinders strung on small cords of sinew; likewise, the tradition continues, the quills of large feathers, cut off and strung on cords, were also used as tokens, pledges, or vouches for the good faith of the messenger or speaker.

Fresh-water shells were substituted by Hiawatha for these things. Coming to a small body of water, he saw its surface literally covered by ducks swimming about. He went near and exclaimed, "Do you not attach any importance to my mission?" At once the ducks flew up into the air, bearing up with them the water of the lake. Hiawatha at once went down into the bottom of the lake, thus made dry, and there he saw many shells of various colors. These he gathered and placed in a skin bag which he carried. When the bag had been filled he returned to the shore of the lake, and selecting a suitable place sat down there and, tradition says, strung the 28 strings with their messages, which are employed in the ritual of the condoling and installation ceremony of the league to this day, although these fresh-water shells have long been replaced by wampum beads.

It is thus seen that this tradition makes Hiawatha the designer of the pledges for this rite, although the matter of the tradition shows that this cannot be true, because the use of a set number of topics of the "comfort," or rather "requickening address," was in vogue among other tribes of the Iroquoian linguistic stock—the Huron, for example.

The name Hiawatha was immortalized by Longfellow in the beautiful poem bearing this name, although there is nothing in the poem that can be predicated of the historical person bearing that name. This was due to the mistake of confusing two names—that of Hiawatha with that of the Iroquoian god, the Master of Life, the one who gives or creates all life, both faunal and floral, on the earth.

Mr. J. V. H. Clark, in his "Onondaga, etc.," is directly responsible for this confusion, for, although Schoolcraft added to it, Mr. Clark brought it to pass in the first instance. In the hands of careless hearers and recorders native Indian names which in fact have no relationship whatsoever are readily confounded. In the Mohawk dialect of the Iroquoian stock of languages (and in all others of this stock using the r-sound in their phonetics) Teharonhiawagon approximately records the sounds in the name of the Life God or the

Master of Life; but this name in Onondaga (and in all other dialects of this stock, which do not use the r-sound), becomes Dehaenhiawagi. This name, misspelled, appears in print as Ta-oun-yawat-ha, Thannawege, Taonhiawagi, and Tahiawagi, etc.; but between these and the dubious attempts to record the native original for the Anglicised Hiawatha—namely, Tahionwatha, Taoungwatha, Ayonhwatha, Hayenwatha, Hayonwentha, etc.—there is no relationship whatever. But Clark, misled, perhaps, by otosis and misconception and by a confused tradition, identifies in direct statement the two names and the two persons.

Schoolcraft, when gathering material for his *Notes on the Iroquois*, received a number of fragmentary mythic tales about the Iroquoian god, the Master of Life and also traditional stories about one of the chief founders of the league. But as these had been confounded by Clark and made to relate to a single individual Schoolcraft indiscriminatingly adopted this intermixture, and added to the mischief by transferring Hiawatha to the region of the Great Lakes, and there identified him with Nanabozho, the Master of Life, or God of Life, of the Chippewa and other Algonquian cognates.

Now, the Mohawk Iroquoian Teharonhiawagon and the Chippewa Algonquian Nanabozho are approximately identical mythic conceptions, but neither has in fact or fiction any feature predicable of Hiawatha. Schoolcraft's *The Hiawatha Legends*, to which we owe the charming poem of that name by Longfellow, were chiefly mythic tales and fiction about Nanabozho, the Chippewa Master of Life, but which contain nothing about Hiawatha, an Iroquoian chieftain of the sixteenth century.

Were Europeans of some day in the future shown a great narrative of French epic adventure in which Prince Bismarck, the despoiler of France, should appear as the central and leading Gallic hero in the glory and triumph of France, the absurdity and error would not be greater or more towering than in these blunders of Clark and Schoolcraft concerning Hiawatha and the Master of Life of Iroquoian and Algonquian mythic thought.

In the establishment of this highly organized institution the swart statesmen, Deganawida, Hiawatha, and their able colleagues, and the equally astute stateswoman, Djigonsasen, a chieftainess of the Neutral nation (or tribe), then very powerful and warlike, united their efforts in bringing to a successful issue, notwithstanding bitter intratribal opposition, a peaceful revolution in the methods, in the scope, in the forms, and in the purposes of government extant among their respective peoples—a much needed reform which was at once fundamental and far-reaching in its immediate effects and future possibilities.

The dominant motive for the establishment of the League of the Five Iroquois Tribes was the impelling necessity to stop the shedding of human blood by violence through the making and ratifying of a universal peace by all the known tribes of men, to safeguard human life and health and welfare. Moreover, it was intended to be a type or model of government for all tribes alien to the Iroquois. To meet this pressing need for a durable universal peace these reformers proposed and advocated a constitutional form of government as the most effective in the attainment of so desirable an end.

The founders of the league, therefore, proposed and expounded as the requisite basis of all good government three broad "double" doctrines or principles. The names of these principles in the native tongues vary dialectically, but these three notable terms are expressed in Onondaga as follows: (1) *Ne' ' Skěñ'no*", meaning, first, sanity of mind and the health of the body; and, second, peace between individuals and between organized bodies or groups of persons. (2) *Ne' ' Gai'hwiyó*", meaning, first, righteousness in conduct and its advocacy in thought and in speech; and, second, equity or justice, the adjustment of rights and obligations. (3) *Ne' ' Gā's'hasdē'sā*", meaning, first, physical strength or power, as military force or civil authority; and, second, the *orenda* or magic power of the people or of their institutions and rituals, having mythic and religious implications. Six principles in all. The constructive results of the control and guidance of human thinking and conduct in the private, the public, and the foreign relations of the peoples so leagued by these six principles, the reformers maintained, are the establishment and the conservation of what is reverently called *Ne' ' Gayančē'sā'gō'nā*—i. e., the Great Commonwealth, the great Law of Equity and Righteousness and Well-being, of all known men. It is thus seen that the mental grasp and outlook of these prophet-statesmen and stateswomen of the Iroquois looked out beyond the limits of tribal boundaries to a vast sisterhood and brotherhood of all the tribes of men, dwelling in harmony and happiness. This indeed was a notable vision for the Stone Age of America.

Some of the practical measures that were put in force were the checking of murder and bloodshed in the ferocious blood-feud by the legal tender of the prescribed price of the life of a man or a woman—the tender by the homicide and his clan for accidentally killing such a person was 20 strings of wampum, 10 for the dead man and 10 for the forfeited life of the homicide; but if the dead person were a woman, the legal tender was 30 strings of wampum, because the value of a woman's life to the community was regarded as double that of a man. And cannibalism, or the eating of human flesh, was legally prohibited. Even Hiawatha forswore this abominable practice before taking up the work of forming the league.

The institution of the condoling and installation council was important and most essential to the maintenance of the integrity of their state, for the ordinances of the league constitution required that the number of the chiefs in the federal council should be kept intact. So to the orenda, or magic power, believed to emanate and flow from the words, the chants and songs, and the acts of this council, did the statesmen and the ancients of the Iroquois peoples look for the conservation of their political integrity and for the promotion of their welfare.

So potent and terrible was the orenda of the ritual of the mourning installation council regarded, that it was thought imperative to hold this council only during the autumn or winter months. Since its orenda dealt solely with the effects of death and with the restoration and preservation of the living from death, it was believed that it would be ruinous and destructive to the growing seeds, plants, and fruits, were this council held during the days of birth and growth in spring and in summer. To overcome the power of death, to repair his destructive work, and to restore to its normal potency the orenda or magic power of the stricken father side or mother side of the league, and so making the entire league whole, were some of its motives.¹

In eulogizing their completed labors the founders of the league represented and described it as a great human tree of flesh and blood, noted for size and length of leaf, which was also represented as being set up on a great white mat—that is to say, on a broad foundation of peace, and whose top pierced the visible sky. It was conceived as having four great white roots composed of living men and women, extending respectively eastward, southward, westward, and northward, among the tribes of men who were urgently invited to unite with the league by laying their heads on the great white root nearest to them. It was further declared that should some enemy of this great tree of flesh and blood approach it and should drive his hatchet into one of its roots, blood indeed would flow from the wound, but it was said further that this strange tree through its orenda would cause that assailant to vomit blood before he could escape very far. In certain laws the federal chiefs are denominated standing trees, who as essential components of the great tree of the league are absorbed in it, symbolically, and who are thus said to have one head, one heart, one mind, one blood, and one dish of food.

The ties which unite a tribe with its gods—ties of faith and the bonds of duty and obligation of service which bind the persons of the tribe unitedly together, ties of blood and affinity—are the strongest operative among tribal men and women. Every unde-

¹ See the writer's article on this subject in *Holmes Anniversary Volume*, Washington, 1916.

veloped people or human brood of one blood and origin live under the direct care and special providence of its gods and so seeks to maintain, by suitable rite and ceremony, unbroken and intact relation and converse with them. From the legends and traditions of such a people it is learned that all that they have, all that they do ritually, and all that they know, they have received freely by the grace of their gods. The tribes of the Iroquois people were no exception to this rule.

In Iroquois polity there was a definite separation of purely civil from strictly religious affairs. So the office of civil chief was clearly marked off from that of prophet or priest, and in so far as an incumbent was concerned it was the gift of the suffrages of a definite group of his clanswomen, and so in no sense was it hereditary. The office was hereditary in the clan, and strictly speaking in some family line of the clan. The civil assembly, or the council of chiefs and elders or senators, was in no sense a religious gathering, notwithstanding the custom of opening it with a thanksgiving prayer in recognition of the Master of Life—a strictly religious act. The officers of the religious societies and assemblies were not the same as those who presided over the councils of chiefs. And it is noteworthy that a federal chief must not engage in warfare while clothed with the title and insignia of office; to do so he was required to resign his office of federal chief during his absence on the warpath.

* * * * *

There is a dualism in organization running through all public assemblies of the Iroquois peoples living under the earlier culture. It must be noted that this dual character of the tribal and league organization does not rest on blood ties or affinity, or on common religious rites, but rather on the motive to dramatize two dominant principles which appear to pervade and energize all observed sentient life. In short, this dualism is based primarily on certain mythic concepts regarding the source of life and the most effective means of conserving it on earth among men. Among the Iroquois people of to-day the knowledge of the reason for the persistent dual organization of tribe and league has been lost completely. But a painstaking analysis of rituals and of certain terms appearing in them gives us a trustworthy clue to the reason for a dualism in organization. The reason thus deduced is the need for embodying in the tribal organic unity the principles of the complementary sexes as organic factors in order to secure fertility and abundant progeny. In short, it was deemed imperative to recognize the male and female principles of the biotic world and all that such recognition implies—fatherhood and motherhood and the duties and obligations arising from these states, as defined in Iroquois thinking. This dualism makes the life of the father and the mother endure with that of the

clan of which either is a member. The same is true of sonship and daughtership.

This ascription of sex to groups—organic groups—of persons measurably explains the potent motive which underlies the apparently artificial rule of exogamy that controls certain groups of persons as against other like groups of persons.

By the prophet-statesmen of the early Iroquois and their cotribesmen the League of the Five Tribes as an institution—as an organic unity—was conceived at times as a bisexed being or person; i. e., as an organic unity formed by the union of two persons of opposite sexes. To those early prophet-statesmen life was omnipresent—obtrusively so, for, unconsciously, their ancestors had imputed it to all bodies and objects and processes of the complex world of human experience. But it must be noted that the life so imputed was human life, no other. And so as an institution the league was conceived as an animate being, endowed with definite biotic properties and functions, as the male and female sexes, fatherhood and motherhood, mind, eyesight, dream power, human blood, and the possession of guardian spirits for its two highest organic members.

In the ritual of the installation of chiefs in all the many addresses and chants and songs, each of the two constituent organic members, the father and the mother sides, is addressed as a single individual. In the famous so-called six songs of the mourning and installation council, which are so dramatically sung by a chief who represents the dead chief or chiefs to be resurrected, each of the two constituent persons is addressed, but in the fifth song, the totality, the league as a unity is addressed as a person, to whom is sung this farewell song of the departing chief. This is done evidently to secure the departure of the ghost in peace.

Again, the lamenting cry of "hai'i," hai'i," which is so tediously recurrent in all the chants and songs, but one, of the mourning and installation council, is employed, it is said, in order to console the spirits or spirit of the dead. The reason for using this particular cry is that it is reputed to be that made by spirits when moving from place to place. But it was believed that should this cry be omitted in the rituals the displeasure of the departed spirits would be manifested in an epidemic of diseases affecting the spine and the head.

The duties and obligations of the clan or sisterhood of clans of a father to the clan of his children were by the founders of the league made a part of the functions of the male member, or sisterhood of tribes, in the organic structure of the league. In like manner the duties and obligations of the clan or sisterhood of clans of a mother to the clan or sisterhood of clans of the father of the children were made a part of the functions of the female member, or sisterhood of tribes, in the organic structure of the league. Thus the two con-

stituent members of the highest order in the structure of the league were the female group of two tribes and the male group of three tribes, respectively representing the mother and the father sides, the female and male principles, the whole representing the union of fatherhood and motherhood for the promotion of the life force and welfare of the community.

The term *agadoñ'ni*, meaning "my father's clansmen," has two very distinct applications—first, to the clan of one's father, and, second, to the male or father side of the league. And the term *kheya'da'wč̃*, meaning "my offspring," also has two very different applications—first, to the clan of the children's mother, and, second, to the female or mother side of the league. There were three tribes which constituted the male or father side of the league structure—namely, the Mohawk, the Onondaga, and the Seneca; and two tribes, the Oneida and the Cayuga, originally constituted the female or mother side of the league. To the Onondaga, however, was given the noteworthy distinction of presiding over the deliberations of the federal council. This they did of course through their chiefs; but these chiefs did not have the right to discuss the question at issue. This apparent primacy of the Onondaga carried with it the office of fire keeper and the presiding officer of the federal council.

It must be noted that the mother or female complex of tribes and the father or male complex of tribes were held together by the exercise of certain rights and the performance of certain duties and obligations of the one to the other side.

The federal council, sitting as a court without a jury, heard and determined causes in accordance with established rules and principles of procedure, and with precedent.

THE PROBLEM OF DEGENERACY.¹

By A. F. TREGOLD.

By the term "degeneracy" is usually understood any marked falling away, either morally, mentally, or physically, from the average condition of the nation or race. Thus, among civilized peoples, the habitual criminal and the morally perverse, the mentally unstable and insane, the physically weak and ill-developed, are often spoken of as "degenerates." But these various conditions may be dependent upon widely different causes, and in the endeavor to make this clear, and to attach, if possible, a more precise meaning to the word, it will be well to refer to some points regarding individual development.

In a previous article in this Review (October, 1913) it was stated that the development of the individual is dependent upon two factors—namely, the *seed* from which he is derived and the *soil* in which that seed is grown. These are commonly spoken of as heredity and environment, or nature and nurture; perhaps they are more accurately defined as intrinsic potentiality and extrinsic stimulation. It was shown that the highest degree of development necessitates the presence of a maximum developmental potentiality *plus* an optimum environment. It follows that defective development, of sufficient severity to come within the usual meaning of the word degeneracy, may be caused by a defect in either or both of these contributory factors. As examples of such inferiority due to defects in the environment, I may refer to the intellectual poverty and the immorality or moral obliquity which result from inadequate or improper training and instruction during youth and adolescence; also to the stunted growth and poor physique, often the actual disease and deformity, which follow insanitary surroundings, deprivation of suitable food and exercise, and general neglect or mismanagement, during the early months and years of development. These are conditions with which most of us are only too familiar; and probably no one would deny that under such adverse surroundings the individual must fail to attain that degree of development of which he is innately capable.

On the other hand, we are equally familiar with instances in which, in spite of the most hygienic surroundings, the best education and

¹ Reprinted by permission from the Quarterly Review, July, 1917.

the most careful upbringing, the individual never reaches the average developmental plane. Many children of this type die within a few months of birth, not so much from actual disease as simply because they have not strength to live. Others survive, but are physically, mentally, or morally deficient. Doubtless in some cases there may be obscure faults in the environment, but there are very many in which this is not so, and in which there are clear indications of an innate defect of potentiality; in other words, of the fault being in the seed and not in the soil. The great bulk of the mentally deficient belongs to this group.

The difference between these two types of so-called degeneracy, however, lies not only in their mode of causation, but in their ultimate results. That which is due to an inadequate or adverse environment acting upon the embryo—that is, after fertilization of the germ cell has taken place—is, in most instances, an affection of the cells of the body only. These are incapable of attaining their full development, because some of the necessary external stimuli to that development are lacking. If the want is supplied before the period of growth is past, the arrears may be made up; if not, some degree of permanent defect results. In some cases it is probable that the germ plasm which is stored within the individual, to give rise, in due time, to another generation, may also be affected; but in most instances this is not so. What is produced is a somatic modification only, the germinal potentiality of the seed being unimpaired. The case is entirely different with regard to that type of degeneracy which appears in spite of a satisfactory environment. The defect here is clearly germinal; it is, in fact, a germ variation, and as such is transmissible to subsequent generations in accordance with the laws of heredity.

In view of this important and far-reaching difference between these two types, usually comprehended by the word “degeneracy,” some verbal distinction is clearly necessary. In my opinion that term should be restricted to the latter group, accordingly I venture to define degeneracy as “a retrograde condition of the individual resulting from a pathological variation of the germ cell”; and it is in this sense that it will here be used. Perhaps the most convenient word to denote the somatic modification arising from a defective environment would be “decadency.”

Degeneracy, then, is the expression of a germ variation. It is generally accepted by biologists that variations of the germ cell tend to be transmitted to subsequent generations. It is doubtful whether this transmission is invariable, and the laws governing it are still very imperfectly known, but, as a broad fact, it is certainly true. It follows that the occurrence of variations is a phenomenon of the utmost importance to the future of the race. Such

variations may be divided into two main groups: Firstly, those which connote an increased potentiality for development in some particular direction, thereby placing the individual at a greater advantage in the struggle for existence. These may be termed "progressive" variations, and they obviously lie at the root of progressive racial evolution. Secondly, those which connote a diminished potentiality for development of such a nature as to impair the survival value. These may be termed "retrogressive" variations and lie at the root of social degeneracy. It is with this latter class only that we are now concerned.

The prevention of the perpetuation of these retrogressive variations is clearly a social problem of great moment, and comprises what is known as restrictive or negative eugenics. But the problem of their causation is even more important; for restrictive eugenics, however complete, can never prove entirely satisfactory so long as degenerates are still being produced *de novo*. Accordingly it is chiefly with the question of causation that it is proposed to deal.

There are three chief views as to this causation, which may be discussed seriatim. The first is, that degeneracy is not the expression of any new germinal change, but the perpetuation of a defect which has existed in certain strains or stocks of the human race from the very beginning or from a Simian ancestry. This idea has probably occurred to most thinkers on the subject, but it has recently again been advanced by Dr. C. B. Davenport, of America. Doctor Davenport,¹ speaking of the origin of mental defect, says:

The conclusion is forced upon us that the defects of this germ plasm have surely come all the way down from man's apelike ancestors, through 200 generations or more. The germ plasm that we are tracing remains relatively simple; it has never gained, or only temporarily at most, the one or the many characteristics whose absence we call (quite inadequately) "defects." Feeble-mindedness is thus an uninterrupted transmission from our animal ancestry. It is not reversion; it is direct inheritance.

Now, with regard to this theory, we must either assume that the defect has been present since the very origin of life, or that it has appeared at some subsequent period. On the former view it is presumed that the innate potentiality only sufficed for the attainment of a certain low stage of mental development; degeneracy, however, is no mere evolutionary arrest at some particular phase; it is usually seen as, if I may venture to use such a term, a progressive retrogression of certain stocks. If, however, we admit that the variation has made its appearance at some later stage of evolution, then this theory affords no explanation as to its causation;

¹ "The origin and control of mental defectiveness," 1912.

it simply pushes the inquiry back to that period, "200 generations or more."

In this connection it may be remarked that atavism is not uncommonly invoked as the explanation of feeble-mindedness, which is one of the most prevalent forms of degeneracy. It is contended that, for some reason or other, these persons reproduce, or hark back to, a stage of mental development which was typical of savage or prehistoric man, but from which normal mankind have evolved. It is inferentially suggested that, although mental defectives are incapable of holding their own in a civilized community, they would not be incapable of so doing among these more primitive types. I can not accept this view. I find it exceedingly difficult to believe that the feeble-minded members of a civilized community would be any better able to hold their own among a community of savages than they are in their present environment; and I find it still more difficult to imagine that such persons represent a normal developmental phase in the mental evolution of the human race.

In this place also reference may be made to a recent work by V. A. Moschkoff (*Neue Theorie von der Abstammung des Menschen und seiner Degeneration*). This author looks upon the whole of mankind as being blended in various degrees from two types—white diluvial man and Pithecanthropus. He describes the physical, mental, and moral characteristics of these types with a minuteness which puts the deductive ability of Owen completely in the shade, and which might, indeed, almost be the outcome of a personal acquaintance with these primeval beings in the flesh. White diluvial man would appear to have been a sort of Apollo, the possessor of many beauties and virtues, and of a body which was in every way more perfect than any now existing. Pithecanthropus, on the other hand, was a speechless, repulsive being, apparently somewhat midway between an African pygmy and a modern gorilla. According to Moschkoff, not only is degeneracy, as seen in idiots, cretins, and certain ethnic groups, due to a reversion to the pithecanthropic element, but the alternate expression of the characters of these two stocks takes place at different ages in the same individual and at different cycles in the life of the nation, and so leads to successive alterations of individual character, and even to progressive and retrogressive changes involving the whole community. Even civil wars and internal dissensions, which the sociologist usually attributes to economic causes, are claimed by the author as being due to the swing of the pendulum bringing into play a preponderating pithecanthropic element. And the pendulum would appear to swing so regularly that, given the requisite biological data, he would even be able to forecast which would be the fat and which the lean years of a nation's future. Can anything more be expected of science than this? ,

The second theory of causation is that these retrogressive variations are not caused, but arise of themselves; in other words, that they are "spontaneous" in origin. Thus, in the Report of the Royal Commission on the Feeble-minded the following statement occurs:

Both on the ground of fact and of theory there is the highest degree of probability that feeble-mindedness is usually spontaneous in origin; that is, not due to influences acting on the parent.

Now, as Huxley remarked many years ago, to say that a variation is spontaneous is simply to express our ignorance of its causation; and it is obvious that this theory of "spontaneous variation" is extremely unsatisfactory. The more we learn of the phenomena of nature, the more do we find evidence of law and order; and it would be strange, to say the least, if chance and not law should control what is probably the most important happening in the whole of nature.

The third view is that retrogressive germ variations have neither existed *ab initio* nor are spontaneous in origin, but are produced by the operation of natural processes and in obedience to natural laws. In my opinion this is not only the most reasonable view in itself, but the only one which is supported by definite evidence; and, although it is not yet possible fully to explain the manner of production of these germ variations, it is possible to advance certain considerations which at least possess the merit of carrying us a step further toward the elucidation of this problem.

If we pass for a moment from the germ cells to consider the cells of the body, we find that retrogressive changes occur under two conditions: Firstly, in consequence of an endogenous decline of their vitality; secondly, through the action of external agencies. The former of these changes occurs in old age. By this is not meant old age as expressed by years; some persons are old at 40, others still young at 80. What is meant is that condition of senescence which results from the exhaustion of the inherent vitality of the cells. They are unable to function because they have come to the end of their physiological banking account. Decay arising from without is best exemplified by the action of such inorganic and organic poisons as alcohol, lead, and phosphorus, or by toxic bodies produced by certain microorganisms. These agents may bring about such a deterioration of important cells and tissues that the death of the individual results. The problem we have to consider is whether the germ-cells may be affected by similar agencies. May they undergo pathological variation in consequence of senescence? May the same result be caused by adverse factors of the environment?

To begin with the first of these questions—since the modern conception of the continuity of the germ plasm has become popular, it is not infrequently said that this plasm is "immortal." But even if

it be granted that germ plasm existing to-day is the lineal descendant of plasm which has existed since the origin of life, this statement requires some qualification. The unexpended germ cells not only die, of course, at the death of the individual, like any other piece of protoplasm, but they may die, or at all events lose their capacity for reproduction (which comes to the same thing), while the ordinary somatic cells are still alive. This commonly takes place in women between the fortieth and fiftieth year. Now, it has been noticed by several observers that children born toward the end of the female reproductive period tend to be feebler than those born while the generative organs are in full vigor. Possibly this, in part, may be due to a senility of the maternal tissues which nourish the seed, but it is equally likely to be due to a senility of the seed itself, so that there is some ground for thinking that senescence may be a possible cause of pathological germ variations.

Again, there are certain infusoria, which, while ordinarily multiplying by fission, from time to time undergo a form of conjugation not unlike that which occurs between the sperm and germ cells in human beings. It was shown by Maupas that, if this periodical conjugation is prevented, the offspring resulting from subsequent fissions gradually undergoes a form of degradation until the whole group eventually becomes extinct. Prof. Marcus Hartog argues from this and similar researches made by other inquirers that conjugation or fertilization plays an important part in warding off senescence. Is such introduction of fresh blood necessary to ward off senescence and prevent germinal impairment in the case of higher animals, human beings in particular? With regard to certain domestic animals, there is reason to think that close in-breeding is followed by a gradual deterioration of offspring; and experienced breeders are practically unanimous that the effect of this is to produce debility, abnormalities, and eventually sterility. As Sir Francis Darwin says, "it is generally admitted that degeneration either in constitution or in other ways does ultimately ensue; so that at any cost the breeder is absolutely compelled to admit blood from another family or strain of the same race." In the case of human beings, however, in-and-in breeding to this extent is practically unknown; and it is therefore unlikely that senescence of the germ plasm from such a cause plays any practical part in the production of degeneracy. At the same time it is to be remarked that the effect of consanguineous marriages is to intensify any existing defect; and the same is true where mating is rigidly restricted to the members of any one small section of society. We are apt nowadays to bewail the not infrequent union of members of our old and formerly exclusive aristocracy with chorus girls and the like. The process may be attended with a serious decline in "form" and manners; but it is possible that it may possess

physiological compensations which are beneficial to the race as a whole.

We have now to consider the question of the modification of the germ plasm by the environment. Fifty years ago few scientific persons would have doubted this; and even to-day it is probable that most medical men would say that their clinical experience supported such a view. But in those days it was supposed that the germ cells arose, by some means or other, from the body cells; it followed that their condition was dependent upon the condition of the body cells, and the production of germ variations through the environment was a necessary and logical sequence. But recent writers, particularly Professor Weismann, have proclaimed the "continuity" of the germ plasm; they have contended, in other words, that it is not produced anew in each individual, but is an independent plasm, which is handed on from generation to generation as a separate entity; and it is consequently argued that the germ plasm is immune to its surroundings. Some writers have even gone so far as to say not only that the environment has, in fact, no influence in the production of germ variations, but that it can not have any such influence, because, if it had, it would be subversive of the whole doctrine of evolution. Since this argument strikes at the very root of what I conceive to be the origin of degeneracy, it will be well to consider the basis upon which the assertion is made. And in this connection I can not do better than quote the words of Dr. Archdall Reid, who is perhaps the most strenuous advocate of this view. Dr. Reid says:

If this theory that germinal changes may be caused by waste products, circulating toxins, and the like, is correct, all races affected by any sort of disease should drift steadily toward extinction. Again: If disease produces any germinal change, then, no matter how small and imperceptible the differences between one generation and the next, * * * the constant accentuation of the alteration during hundreds, perhaps thousands, of generations must make it at last manifest and unmistakable. * * * The facts are decisive; nearly all human races have been exposed to disease for thousands of years, and in no instance is there to be found an iota of evidence that any race has, as a consequence, become degenerate. ("The Laws of Heredity, pp. 260-262.)

Now, at first sight these statements may appear very plausible; but a little reflection will show them to be really fallacious in that they entirely disregard one important consideration—namely, the possibility that the vulnerability of the germ plasm may vary greatly in different individuals. In the case of the ordinary tissues and organs of the body—the somatoplasm—there is no doubt whatever on this point; and one of the best-established facts in medicine is that of the varying resistance to disease presented by different individuals. Thus, one person will rapidly succumb to tuberculosis, influenza, pneumonia, or other toxic process; another will escape death but evince considerable subsequent deterioration; while a third will re-

cover without any permanent ill effects. It is surely not unjustifiable to consider that similar differences of vulnerability may exist in the case of the germ plasm. Adverse factors of the environment will then not be operative upon the germ plasm of the whole community, but only upon that of the susceptible portion; and it will no more follow that "all races affected by any sort of disease should drift steadily toward extinction" than it follows that all persons affected with tuberculosis, influenza, or other disease will necessarily die of those complaints. Further, not only may some germ plasm be practically immune, but plasm which is susceptible may be influenced to varying extent, both quantitatively and qualitatively, thereby giving rise to many different forms of variation and degrees of degeneracy.

As a matter of fact this is precisely what happens; and the manifestations of degeneracy as seen in daily life vary within very wide limits. In some instances the variation is so pronounced as to interfere seriously with the survival value of the resulting offspring. Such individuals will then be eliminated by natural selection, provided this is sufficiently rigorous, so that, far from being subversive of the doctrine of evolution, the process is one which actually conduces to racial evolution. It may happen, however, that the variation is much less pronounced and the social environment not sufficiently rigorous to bring about elimination. Such individuals will then not only be enabled to survive, but will intermarry with those whose germ plasm is unimpaired, with the result that a dilution of the morbid process may take place so far as individual members are concerned, but there will be a more widespread dissemination throughout the community.

As will presently be shown, these milder manifestations of degeneracy occur more particularly in the central nervous system. They involve those parts of the nervous system concerned with the higher processes of mind, and they take the form of a diminished mental potentiality, a lessened vigor and initiative, a want of balance, and a loss of control. The social expression of these changes is seen in an incapacity of the community for sound government and legislation, for organization and for social progress, and an inability to compete with more vigorous neighbors, both in the arts of peace and in those of war, the natural termination of which is social decline or even disruption. It is exceedingly questionable if any student of history will be found to maintain that there is not "an iota of evidence" of the past existence of such degeneracy.

As to why the germ plasm of different individuals should vary in susceptibility to the action of adverse factors in the environment, we know very little. It is not inconceivable, indeed it is a reasonable assumption, that its state of nutrition may be subject to change,

and that this may determine its immunity or vulnerability; or the same result may be brought about by the absence or deficiency of some internal secretion. This question is one of great moment, but it is too intricate to enter upon in this place.

The fact is, then, that not only are there no a priori reasons against the modification of the germ plasma by the environment, in spite of much reiteration to the contrary, but there are many such reasons in favor of this modification taking place. Doubtless the germ material possesses a considerable degree of resistance to the action of the environment; for, were it otherwise, and did it reflect every transient change, racial stability could hardly exist. But there is a great difference between some degree of resistance and absolute immunity; and when we remember that after all the germ plasma is still living protoplasm and consequently dependent for its sustenance upon the quantity and quality of the fluids supplied to it, the view that it can lead a charmed life, utterly uninfluenced by any condition of its host, is untenable. As Beard says, "the germ cell must react to and be influenced by its environment"—a conclusion not only accepted by most competent biologists of the present day, but acquiesced in by Weismann himself.

However, the question is no longer one of speculation and a priori reasoning. Whatever may be asserted of the theoretical impossibility that the germ cell should be adversely affected by its environment, there is now very clear evidence that it is so affected; and to some of this evidence we may briefly refer. One of the earliest observations (1861) was that of Dr. Constantin Paul regarding the effect of lead. This observer found that out of 32 pregnancies, in which the father alone suffered from lead poisoning, the mother being free from that condition, 12 of the children were stillborn, 8 died during the first, 4 during the second, and 5 during the third year of life, while another died later in childhood. Similar data were published by Lizé (1862) regarding workers exposed to the fumes of nitrate of mercury. Out of 12 pregnancies in which the father alone was exposed, there were 4 stillbirths; of the remaining 8 children, 3 died before the fourth year, and only one of those who survived could be described as vigorous. The toxic effects of alcohol upon growing protoplasm are well known; and, since experimentation with this is comparatively easy, it has naturally formed the subject of many investigations. One of the most recent is that by Stockard upon guinea pigs, by which it was shown that the net result of 24 matings of alcoholized fathers with normal mothers was only 5 surviving offspring, or no more than might have been expected from a single pairing of two healthy animals; and, further, that at the age of two months these 5 survivors were only half the usual size. Dr. E. Bertholet, after a series of microscopical exami-

nations in 120 alcoholic and nonalcoholic human beings, was able to demonstrate very clear differences, and to assert that "the hurtful influence of chronic alcoholism upon sexual glands is not to be denied." Similar results have been obtained with other poisons; and during recent years it has also been shown that germ variations may be induced by temperature (Sumner, Bordage, Tower) and by the injection of chemicals into the immature ovary (Macdougall). Finally, from inquiries which I have lately made into the effect of X rays, there seems to be no doubt that males working with unprotected tubes are rendered temporarily sterile owing to the action of the rays upon the sperm cells. If this and other agencies can thus bring about the death of the germ cell, it is a justifiable inference that smaller doses can so injure it as to produce a living but impaired offspring; and the earlier observations above quoted show that this is actually the case.

In view of the evidence which is now available and is daily increasing, it is impossible to deny that the germ cells may be adversely affected by the environment. As to the actual causal agents of this change in human beings our knowledge is still incomplete. My own observations lead me to think that alcoholism, tuberculosis, and venereal diseases play an important part. But there may be many others with which we are as yet unacquainted, and which will certainly be brought to light when once we discard the bogey of "spontaneous variation," and seek them in a true scientific spirit, devoid of preconceived notions as to what may be possible and what impossible.

The important question now arises as to the nature of the germinal change which is thus induced. In spite of the many researches of recent years, we still know very little about the physical basis of inheritance; but this much is certain, that, in some at present mysterious way, the germ cell contains "representatives" or "determinants" of all the variable parts of the body of the offspring to which it subsequently gives rise. Perhaps the best way of regarding these is that of a series of directive forces or specific energies, each of which is concerned with directing the growth of a particular tissue. On this hypothesis we may assume that the effect of toxic agents is to reduce this innate potentiality, and to bring about what may be termed a devitalization, or an impairment of the whole, or of certain specific, energies of the germ cell. This will not only be operative in the case of the immediately resulting offspring, but, since it is fundamental, may involve subsequent generations. This is in nowise antagonistic to the view of germ continuity.

But the different organs of the human body, as they exist to-day, vary greatly in what may be called their antiquity. There are some—for instance, the circulatory system—which have undergone

comparatively little change with the evolution of the human race through many lower species. There are others, such as the nervous system, which have undergone a very great elaboration, probably even in man himself. It is legitimate to conclude that the innate germinal potentiality of the systems of less antiquity, which have undergone more recent evolutionary change, will be more liable to alteration under adverse or abnormal conditions of the environment than will the potentiality of those which are more organically fixed and have, in fact, a longer heritage; and hence it will come about that these adverse factors exert a selective influence upon the constituents of the germ cell, being chiefly operative upon the higher parts of the nervous system. At the same time our conception of development can hardly be that of a series of organs each pursuing its own growth independently. It seems likely that a certain mutual interrestraint exists, and that, where the potentiality for growth of one organ or tissue is rendered defective, the lessening of restraint may result in irregularity and overgrowth of contiguous tissues, with the production of gross anatomical anomalies and developmental errors.

When we turn to the manifestations of degeneracy—that is, to the manner in which these pathological variations of the germ cell are revealed in the offspring—we find strong corroboration of these views. Retrogressive variations, manifested generation after generation, are to be found, it is true, in many organs, such as the skin, the eyes, the skeleton, etc.; but the commonest expression of all and by far the most frequent form of degeneracy is seen in a defective and abnormal constitution of the higher parts of the nervous system; that is, in the parts concerned with the functions of mind. The usual medical term for this manifestation of degeneracy is “neuropathic diathesis”; and its physical basis is undoubtedly, as has now been shown by many exhaustive inquiries, an impairment of neuronie potentiality which is germinal in origin and may be transmitted generation after generation.

The manifestations of this neuropathic diathesis vary greatly in their degree and nature. In the slighter forms of impairment, as already remarked, there is simply a lessened durability and diminished power of resisting the stresses and strains of life; a weakening of nerve vigor, a proneness to psychasthenia, and a consequent inability for sustained competition. If more pronounced, there is a tendency to early mental dissolution or dementia, to hysteria, epilepsy, insanity, and other marked psychopathic disorders; while, if still more marked, there are grave defects of anatomical development, resulting in feeble-mindedness, imbecility, or idiocy. It has now been conclusively shown that, while some stocks evince no tendency to any of these abnormal mental states, there are others

in which such conditions occur with great frequency for many generations. Some members of such a stock may be epileptic, others suffer from insanity or marked moral failing, while others may be feeble-minded or even idiots. Since the environment of such persons differs in no material particular from that of the mentally healthy section of the community among whom they live, it is clear that the failing is of the germ cell and is inherited. In many family histories it is possible to trace a definite progressive accentuation of the impairment, and in some even to trace it to its origin. Thus, in persons suffering from the mildest manifestations, neuropathic antecedents are relatively uncommon; but a history of ancestral alcoholism or tuberculosis is frequently found. Among epileptics, evidence of the neuropathic diathesis occurs in about 35 per cent of cases; in the insane this proportion reaches from 50 to 60 per cent; while in the mentally defective it occurs in from 80 to 90 per cent. There is thus an increasing degeneracy, which reaches its culminating point in that condition in which mind has become so reduced as hardly to have an existence, namely, profound or absolute idiocy.

It has sometimes been objected that, since the particular defect of the individual is not identical with that which has existed in his ancestors, it can not be regarded as "hereditary." This, however, is either mere hair splitting or betokens a complete ignorance of the nature of the inheritance underlying these morbid conditions. Of course idiocy, insanity, epilepsy, etc., are no more inherited, as such, than any other human quality or defect. Inheritance consists, not in the transmission of actual qualities as we see them, but in the potentiality to develop those qualities under an appropriate stimulus. Similarly in degeneracy, what is transmitted is not epilepsy, insanity, or mental defect, but a diminished developmental potentiality of the nervous system; in other words, the neuropathic diathesis; and I am of opinion that here also the particular manifestations are in many cases determined by particular environmental factors operating during the period of growth.

It has been stated that the gross forms of mental defect represent the culmination of degeneracy; and hence it follows that individuals so suffering are usually characterized by serious abnormalities of anatomical growth and of physiological function in many parts of the body. These are known as "stigmata of degeneracy." The list of these "stigmata" is a long one, comprising among others, deformities of the brain, eyes, external ears, nose, palate, hands, feet, and many other structures. I must confess that the inclusion of some of the anomalies which have been described amongst the signs of "degeneracy" (as I have defined it) seems hardly warranted.

Apart from the fact that there are so many anatomical variations within the normal range that the abnormal becomes exceedingly difficult to define, many of those which are undoubtedly errors of development appear to me to be more a result of adverse conditions affecting the growth of the embryo than of a real germ variation; and a single so-called stigma of degeneracy is not infrequently found in persons who present no other physiological or psychological abnormality. This is particularly the case with the external ear, also with the deformities known as harelip and cleft palate. At the same time there is no doubt that developmental errors are far commoner in victims of the neuropathic diathesis than in the healthy members of the community; and the presence of numerous "stigmata" is so commonly associated with other signs of germinal impairment which is transmissible—of true degeneracy, in fact—as to be extremely suggestive of that condition.

We see, then, that the chief expression of degeneracy occurs in that part of the organism which is at once the most elaborate, the most recent in phylogenetic development, and the most important—namely, the higher portions of the brain. But it is not usual to find such a person possessed of full or even average bodily vigor; and the majority of degenerates evince in addition a lessened power of resistance to disease and a proneness to early death. Whilst a few persons suffering from the milder degrees may do good work, some even taking rank with genius, there can be no question that the great majority are distinctly inferior, in moral, mental, and physical fiber, to the untainted members of the community. It follows that the presence of any considerable number of such persons in the State must entail a serious diminution in the aggregate of vigor and great economic disadvantages.

What effect have these degenerates upon posterity? Individuals suffering from the more pronounced degrees of degeneracy—idiots and low-grade imbeciles—are usually sterile. Further, there is every probability that, if even the milder grades mated solely among themselves, there would gradually be produced such an accentuation of the morbid process that the disease would work out its own salvation by causing the extinction of the stock. But, as has already been pointed out, the initial impairment does not involve the whole community, and the mating is not thus restricted. Persons suffering from the initial and milder forms of degeneracy mate with the unimpaired, so that the question of the laws governing the transmission of the defect becomes one of great practical social importance.

Our knowledge regarding these laws is still very inadequate, but it may be said that, in the main, most, if not all, modes of inheritance may be referred to one of two groups. In the one the inheritance

is "blended"; in other words, the individual may be looked upon as the result of a mechanical mixture of the germinal material of his two parents. This is, perhaps, best seen in the various shades of skin color (mulatto, quadroon, octoroon) which result from the mating of a white with a negro. In the second group certain qualities or peculiarities of one germ cell seem to dominate over antagonistic qualities of the germ cell of the other sex, so that the individual "takes after" his father in regard to some details, but after his mother in regard to others. As Goethe says:

Vom Vater hab' ich die Statur,
Des Lebens ernstes Führen;
Vom Mütterchen die Frohnatur
Und Lust zu fabuliren.

At the same time an individual who himself shows no indication of any parental peculiarity may yet pass it on to his offspring, constituting what is described as patency and latency, as is seen in hoemophilia and certain other diseases. It seems likely that what is commonly known as prepotency, dominance, and patency and latency, may be embraced within the laws which were first discovered by Gregor Mendel, Abbot of Brünn, 50 years ago, and which are now known as Mendel's Laws. Mendel's conclusions, drawn from experiments on peas, were long unknown to the world; but their re-discovery has given an enormous impetus to similar inquiries, and during the last few years numerous investigations have been made with the object of ascertaining whether his results are applicable to man. With regard to some qualities this has been shown to be the case; and it now seems to be established that such abnormalities as brachydactyly, color blindness, night blindness, and congenital cataract are transmitted in accordance with Mendelian laws. Is this so with the neuropathic diathesis, which we may certainly consider the most important form of degeneracy from the sociological aspect?

Researches which have been made under the auspices of the Eugenics Record Office of America proclaim that this is the case, and that "the fact of the hereditary transmission of the neuropathic constitution as a recessive trait, in accordance with the Mendelian theory, may be regarded as definitely established." But the difficulties and sources of possible fallacy attendant upon such inquiries are so great that one must accept these conclusions with considerable reserve. It is impossible to deal adequately with the question in this place, but it may be remarked that a person may be of neuropathic constitution and yet pass through life apparently normal, owing to the absence of any direct excitant to a mental breakdown; in other words, he may inherit a predisposition to insanity and yet, in consequence of his life being cast amid healthy surroundings devoid of strain, never

become insane. The ascertainment of the number of offspring who are hereditarily affected thus becomes a matter of the greatest difficulty, and yet this is essential in order to prove that the transmission is in accordance with Mendelism. My own experience is that, while all the offspring of two markedly degenerate persons are always defective, the children resulting from the union of a pronounced degenerate with a healthy individual tend to be, not some normal and some abnormal, but all of them of abnormal constitution. If one parent only bears the taint in slight degree, it is not uncommon to find some children affected while others entirely escape; but even here it is by no means rare for all the children to evince a distinct psychopathic failing. Whilst, therefore, it is hazardous to dogmatize on the subject—for the facts are by no means conclusive—the available evidence seems to suggest that the inheritance is more often of the blended than of the Mendelian type.

I have spoken of the pronounced grades of mental defect as being the culmination of degeneracy; but it is not always thus cumulative, and it is possible that the mating of a person suffering from a milder degree of germinal impairment with healthy stock might, after a few generations, lead to the eradication of the impairment and so to regeneracy. But the experiment would be somewhat hazardous for the individual offspring. Severe exciting factors might readily fan the slumbering spark into a violent flame; and this is probably the explanation of many so-called sporadic cases of insanity and even of mental deficiency. Such exciting factors may be supplied by injury during birth, infectious disease during childhood, excess or strain during adolescence or maturity, or indeed any untoward condition of the environment, whether of intra- or extra-uterine life. And, should the germinal impairment be still more pronounced, it seems highly probable not only that mating with healthy stock is powerless to neutralise the defect, but that there is the greatest danger of a considerable reduction of the mental vigor and durability of all the offspring and consequently of a marked decline in the net capacity of the community. It is by such means that I conceive that a nation, while still surviving, may not only lose its power to advance, but may be rendered incapable of successful competition against its more vigorous neighbors and so sink to a lower plane. And when we take into account the neutralization of the force of natural selection which occurs in a civilized as opposed to a more barbarous community, and which prevents the elimination of these unsound members, it is not difficult to understand how it has come about that nations which have reached a high degree of civilization should in course of time have been overrun by a horde of barbarians. For with nations, as with individuals, it is the "fit" who survive.

It may safely be said that the problem of degeneracy has now passed beyond the academic stage, and that its practical importance is recognised by most thoughtful persons. But its pressing nature is still unrealised; and it is, perhaps, not unnatural that, in the midst of the greatest war the world has ever known, it should be regarded as a question which can well await the return of peace. There could be no greater mistake. The military necessities of the country and the large number of casualties have already emphasized the importance of "man power" and directed attention toward the declining birth rate and the conservation of child life. All this is quite right and proper; but it is an incontrovertible fact that the many medical rejections and the system of voluntary service have both led to these casualties being disproportionately incident upon the most fit, and that the general effect of the war has been to augment still further the previously existing tendency toward the survival of the least fit. And there is great danger that an indiscriminate increase in the birth rate, a demand for quantity irrespective of quality, may still further contribute toward this result. Let us make no mistake. The ending of the war will not end international competition; and, if we are to maintain our national or economic supremacy we shall need, not merely men and women, but the best men and women we can produce. If we are to do this, the problem of degeneracy must have a place in any scheme for increasing the birth rate and building up the future manpower of the nation.

HISTORY IN TOOLS.¹

By W. M. FLINDERS PETRIE, F. R. S., F. B. A., D. C. L., LL. D., LITT. D.
Professor of Egyptology, London University.

In modern teaching political history has overshadowed all other aspects of man, and the general history of civilization has not yet received recognition. It matters nothing whether Aristotle, Euclid, Newton, or Pasteur lived under a republic or a despotism; but it is of the first importance in history to know the influence of such thinkers and discoverers. The movement of man's mind in ideas, knowledge, and abilities should be one of the principal and most stimulating subjects in education. This would not be a materialistic limitation, and one side of it has been admirably written already in Lecky's *History of Morals*.

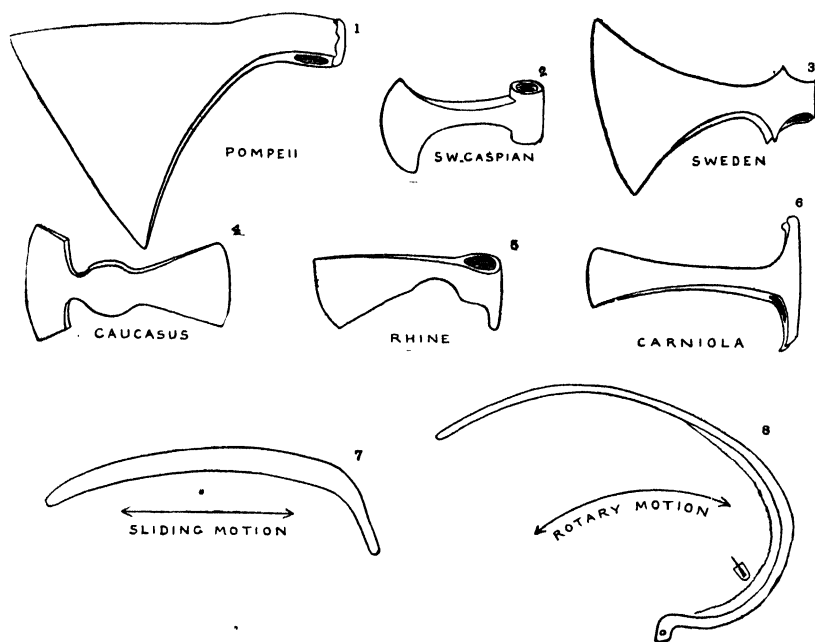
Among the activities of man the development of his means of work must certainly be considered. But while there are many books on offense and defense, arms and armor, there is none that traces the history of the mechanical aids. Thousands of writers have described the sculptures of the Parthenon; not one has described the means used in performing that work. It is a mystery to us how fluted columns with an entasis could be produced, true to a hundredth of an inch in the diameters between the deep groovings.

In taking up the neglected history of tools,² the nature of the materials used is the first view to consider. After the stone ages, the order of metals—bronze and then iron—is tolerably well known. Of late years an earlier age of copper has been noticed in several countries, and this again may be divided into an age of native copper and an age of smelted copper. The use of copper in the American hemisphere was entirely limited to native copper, never smelted; in fact, it was the stone age, including a malleable stone. Native copper is also found in various places in Europe and Asia, and it seems only reasonable to suppose that it would be worked before smelting was discovered. What points to this is the pillowy form of tools in the earliest metal age of most countries. This form could not be cast except in closed molds, but it would be the most natural for hammered native metal. The earliest stage of casting was the

¹ Reprinted by permission from *Science Progress*, July, 1917.

² A first step in historical treatment I have attempted, in a catalogue comparing the tools of Egypt with those of other lands, "*Tools and Weapons*," with 3,000 figures.

mere limiting of outpoured metal in an open mold, and hence flat castings, such as are found in Egypt, and such as appear in other countries after the hammered forms. The order of use of metallic materials, then, seems to be native copper, smelted copper, bronze, iron, steel, and brass. Copper may be hardened by small impurities and much hammering until it is equal to any bronze; the main purpose in using bronze was probably to facilitate casting, especially for closed molds. The *cire perdue* process also needed bronze, and that was a favorite mode of work from early Egypt to early Britain.



A.

Forms of socket: 1, 2, small for hardwood; 3, 4, lengthened for softer wood; 5, 6, for lifting.
Forms of reaper: 7, sliding cut, Swiss; 8, rotated round wrist, Egypt.

In both those lands the metal was run to an astonishing thinness, often only a fiftieth of an inch, a mere film over the sand core.

When the variations of the forms of tools in different countries are compared, much is seen to depend upon climate. In the north (figs. 3, 4), sockets are much larger and deeper than in the south (figs. 1, 2). This is due to the softer and more stringy nature of northern woods, which would be bruised and crushed in the leverage of a small socket. Neither oak nor ash nor beech could compare with the Syrian *shum* for resisting a wrench. The varying purposes also led to very different forms; the slight socket and large blade for a fighting ax, when the blade was not gripped in the cleavage; the splitting ax with a long socket to enable a side wrench to be given;

the cleaving ax with a long back to the socket (figs. 5, 6) to aid in a lifting pull to get it out of the wood. In the agricultural tools there are clear distinctions between the scythe or sickle worked with a sawing motion from the hand at the end of the blade (fig. 7), or the reaping sickle with a circular arc around the wrist which rotates it (fig. 8), or the pruning hook to top off high vine-sprays in the south (figs. 4, 6), or the bill hook to cut copse wood in the north. The different kinds of motion must be considered before we can understand the varying use of each tool. In weapons, similarly, the width of spear or arrowhead is conditioned by the defense. On bare bodies wide cutting blades are the most effective, to attack clothed bodies a narrower blade is needed, and for piercing armor of leather or metal a mere spike is required.

These forms which result from the necessities of use and the guidance of utility may very probably be evolved in many different centers quite independently. We know, in modern times, the Patent Office shows how often a simple thing may be reinvented. The case is different, however, when we look at artistic style; in that, each race or country has its own characteristics which cling to it for ages, and are seldom adopted by others. When a design recurs we can generally trace its descent, sometimes through thousands of years. Sometimes principles of form also have an astonishing persistence. The northern and Syrian peoples used flanged edges to stiffen tools, the Egyptian and most Mediterranean peoples would have none of them. The European and Asiatic used socket holes, the Egyptian always rejected them. The European cast in flat molds, and used punched ornaments; the Asiatic cast in closed molds, and used cast relief ornament. The Asiatic and east European used recurved outlines; the European and Egyptian used straight or simply curved outlines. In all these respects we see a fundamental artistic difference between races.

Another curious aspect of the subject is the worship or reverence given to weapons. Spears were kept in the temples of Italy as means of divination, and immense ceremonial spear-heads are known from early Mesopotamia, Italy, Sweden, Britain, and China. The scimitar was adored in Scythia, and the Quadi adored their swords as deities. The driving of a nail into the temple of Jupiter in Rome was the means of averting pestilence. The double ax was a usual tool, and also a sacred form; ceremonial copies, which could not be hafted, were made in various northern centers, apparently as standard weights.

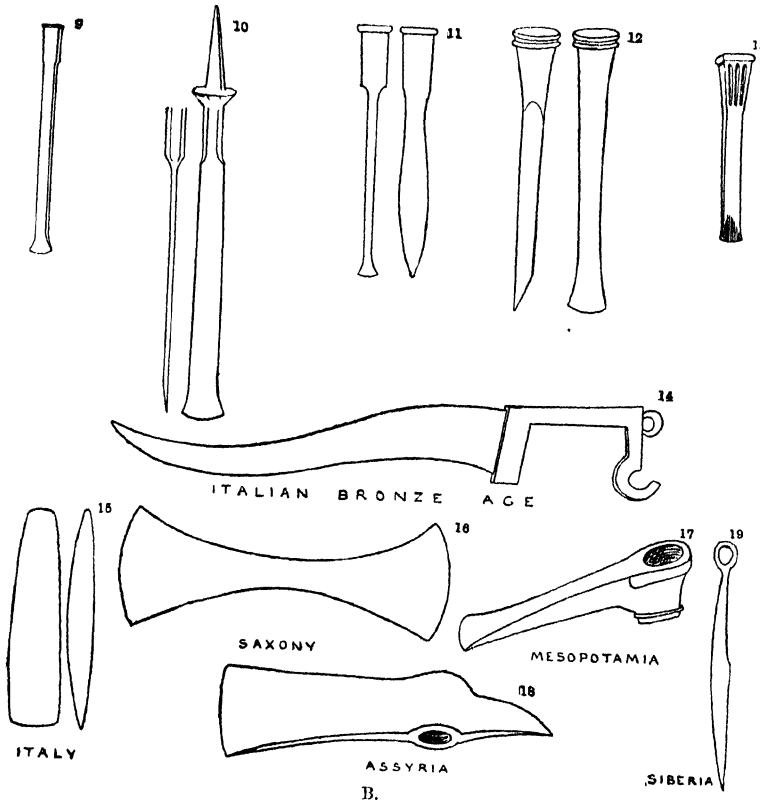
Several stages of inventive activity may be discovered, when a great outburst of new types appears. The most prolific period seems to have been in the later bronze ages, about 900 B. C. The most perfect forms of bronze chisels were then devised (figs. 9 to 13), both

tang and socket chisels, wide chisels, deep mortise chisels, saws with a uniform rake to the teeth to cut in one direction, great knives of a flamboyant form (fig. 14) with double curves—all due to north Italian genius. About the same time, or a little later, the Chalybes on the Assyrian side were developing iron and steel tools on modern lines, socket and tang chisels, saws, rasps, and the early stages of files and centerbits. These were in use about 700 B. C. It is also noticeable how a great wave of ethical ideas appears in that age in Judaea, Greece, and Egypt; it seems to have been a potent stage of thought in many branches.

Some tools which have been, and still are, very usual in other lands, are little known in the West. The adze had a very long career, from the early prehistoric age of Egypt, and is still the common tool of the East. It is often now confused with the axe, under the general name of celt; but it is essentially different, being unsymmetrical in side view, and used across the plane of motion. One common form of it, from about 1500 to 400 B. C., has scarcely been noticed hitherto; it has two projections on the side edge to hold up the lashing which attached it to the handle. It is strange to see how a tool which was commonly used in many countries for a thousand years, has now disappeared from life as totally as the mammoth.

It is too often supposed that because some thousands of years have passed in the history of a tool, therefore we must now be in possession of far better forms than those of past ages. This is true in many cases, but by no means always. The forms of the chisel were perfected 2,500 years ago; and the beauty of work in the bronze age chisels (fig. 10) with perfectly even blades, dished octagonal flanges to the tang, or square sockets ribbed on the outside for strength (fig. 13), has never been exceeded. In other tools there has been an actual loss of good design. The Egyptian form of the Roman shears has one leg detachable for sharpening (fig. 36); it was held in place by two slots engaging T-shaped pins, it could be detached in a second, and yet was quite firm. Such a facility for sharpening is a great advantage, but the form has entirely disappeared. Another Egyptian form was the iron sickle (fig. 8) with a trough groove to hold a strip of steel teeth; this was adapted from the old Egyptian wooden sickle with flint saws inserted, and when steel was valuable it was a great advantage, yet it entirely died out from use. The use of saws and crown drills with fixed teeth of corundum or gem stones, for cutting quartz rocks, was the regular system of work in Egypt 6,000 years ago, and in Greece 4,000 years ago. The cores produced were so perfect and clean-cut that, as Sir Benjamin Baker said, any engineer would be proud to turn out such good work with the best diamond drills. The saws were over eight feet long, sawing blocks of granite $7\frac{1}{2}$ feet long. This splendid work was quite forgotten, the Roman had no such grand tools, and some thousands of years passed before such means were reinvented 50 years ago.

In other cases we can trace the gradual evolution of a tool down to the present day. The carpenter's saw was at first merely a blade roughly hacked on the edge; by 4,500 B. C. it had regular teeth, sloping equally both ways; by 900 B. C. the Italian gave a rake to the teeth to make them really cut in one direction, instead of merely scraping as before. No ancient saw, however, had a kerf, cutting a wider slit than the thickness of the blade; we do not know when that was invented in the Middle Ages. The Egyptian used a push



9 to 14.—Bronze Age inventions of Italy; not used by Egyptians.
15 to 19.—Forms not used by Egyptians.

saw as the earliest form; the pull saw was the only one in the West and the Roman world; the push saw came back into use in the last few centuries, though the pull saw in a frame is still universal in the East. The world did without shears for many ages, cloth being cut with a rounded-blade knife (fig. 34). About 400 B. C. the mechanical genius of Italy invented the shears, which in two or three centuries more were fitted to the fingers, and thus started the scissors. The snuffers in Exodus is a mistranslation; the early tools for trim-

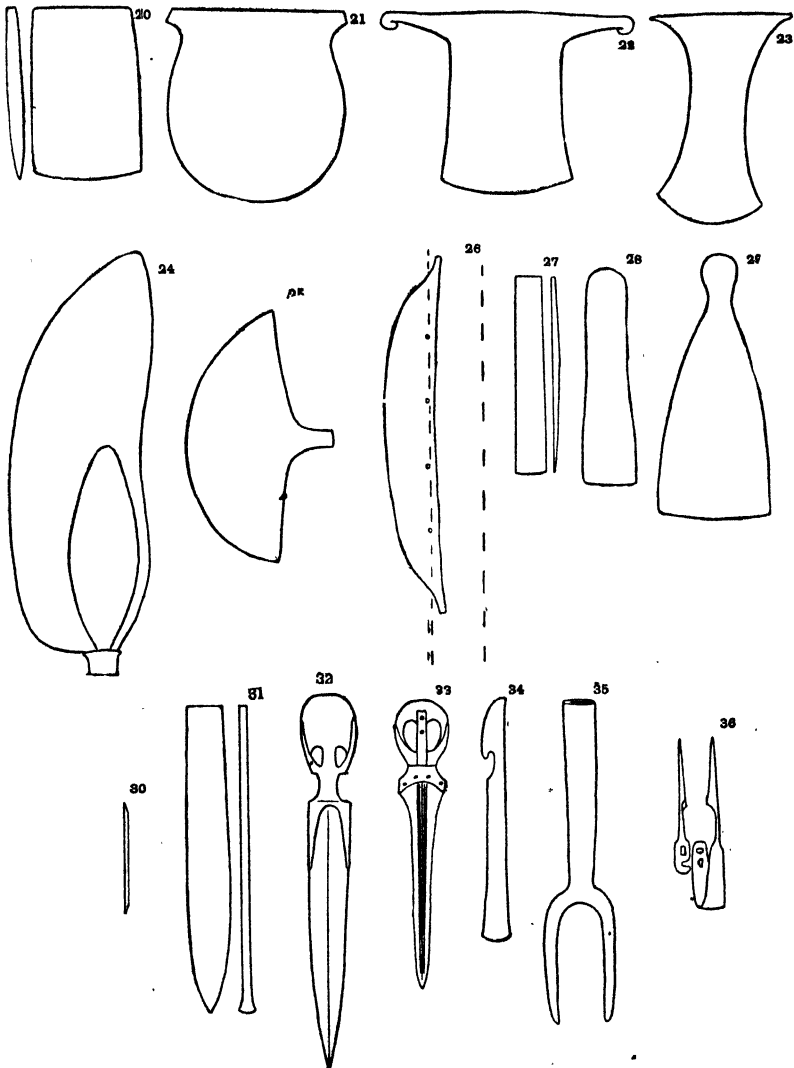
ming a lamp were a small knife with pair of tweezers to trim the wick, and a point to part the strands.

In some cases it is curious to see how long men remained on the brink of an invention. Copper wire was made by cutting and hammering from 5,500 B. C., yet the drawing of wire remained unknown for 6,000 years or more. When the first drawn wire was made is not yet fixed, but it seems to have been unknown to the Romans. Thick beaten wire was made into chain with round links as far back as the second dynasty, 5,200 B. C.; and links doubled up, and looped through each other, appear in the sixth dynasty, 4,200 B. C. Yet chains were not commonly used till much later. The Gauls excelled in such work, as they used chain cables and rigging in place of rope, to resist the Atlantic gales. The screw was a Greek invention, and greatly used by the Romans as a means of motion. Then centuries passed before the nut and screw for fastening was invented; and again centuries before the screw used to fasten wood, which first appears less than 200 years ago.

The light that the distribution of tools throws on the status of ancient civilization is most valuable historically. Not only does the using of certain tools show a level of work and ability, but the resistance to the adoption of forms known elsewhere shows that there was a sufficient ability already in a country. In the present day the forms of common tools differ in various parts of Europe, because each country has a civilization strong enough to carry on without copying another country. A large improvement in one country is the only condition on which other countries will borrow from it, and only then if the changes will suit other conditions. When we find that countries, known to have been anciently in connection, each steadily resisted various forms of tools used by the other, we have good evidence that each civilization was on such a level that it could supply all its wants without great benefit by imitating another. This form of evidence gives some insight into dark ages, of which but little detailed knowledge is preserved; it suffices to show whether countries were far below one another, or on such an equality of work that each was independent.

In Egypt there were many forms of tools and weapons, which were then the standard types, and yet these are never found in other lands. The earliest ax (fig. 20) is a plain square form, from about 6,000-5,000 B. C. Then a round ax (fig. 21) was adopted till nearly 3,000 B. C. After that wider lugs were developed to enable it to be firmly bound on to a handle (fig. 22); and this was made in a lighter and longer form as a battle-ax (fig. 23) used mainly about 1,500 B. C. None of these forms are found in other countries, yet had the lands around Egypt been much behind in their ax forms, they would naturally have been influenced by Egyptian types, as there was

trade intercourse during all these periods. The only adoption of such forms was due to entirely independent reinvention of the ax with lugs in South America, without any intermediate example. The form is a natural one to adopt in hammered copper, for getting a firm attachment to the handle.



C.

20 to 36 —Forms of tools peculiar to Egypt.

Other adaptations of the ax were the large blade of curved outline on the end of a pole (fig. 24), the half-round halberd (fig. 25) and the long edge set in a stout baton (fig. 26) for a cutting blow. All of these were common in Egypt, but never spread elsewhere.

The adz in Egypt was at first a straight long blade of copper with parallel sides (fig. 27). Later it developed a rounded head-end (fig. 28), with contracted neck (fig. 29) to aid in binding it on a handle. Neither of these was copied in any other country.

The chisel was at first sharp at both ends, and held by the middle (fig. 30). Later there is a deep mortising chisel with an equal curve of each face (fig. 31). Neither of these Egyptian forms appears anywhere else.

The dagger, from prehistoric times onward in Egypt, had a crescent handle held in the palm of the hand (fig. 32), so as to use the weight of the arm end-on for a thrust; whereas the European dagger was always held as a knife, across the hand. The Egyptian ornament was by parallel ribs along the axis (fig. 33); in all other countries the ornament is by lines parallel to sloping edges. Some forms are entirely restricted to Egypt, as the cutting-out knife (fig. 34) with a curved blade for cutting linen, the forked spear butt (fig. 35), and, in Roman times, the shears with detachable leg (fig. 36) and the sickle with replaceable teeth (fig. 8).

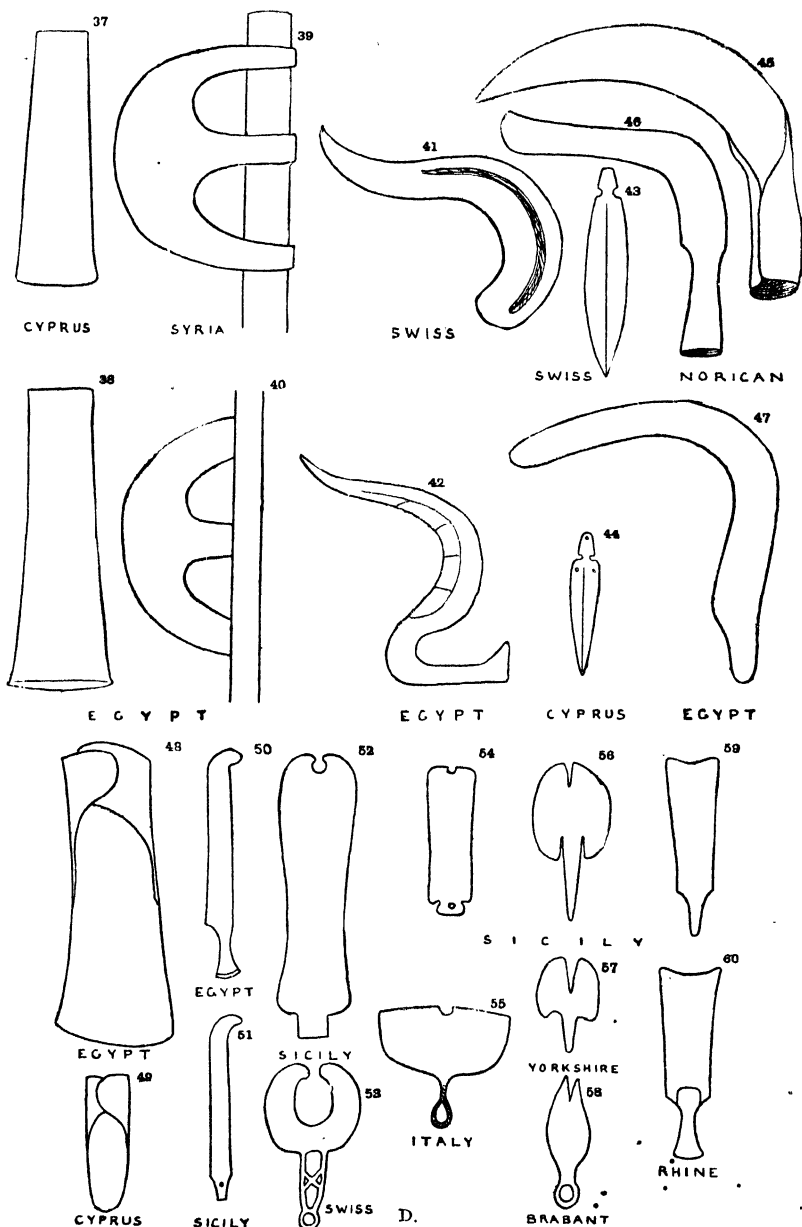
Here, then, are 17 tools and weapons, mostly of general importance and use in Egypt, which were none of them required by the neighboring lands, where there must have been some useful equivalents.

The converse is equally true; many forms were used around Egypt which never were adopted there. In Cyprus and other lands the earliest axes are of a pillowy form (fig. 15), with bulging faces. In Europe the double ax (fig. 16) was not only a tool and a weapon, but also a sacred symbol and a standard weight. In Mesopotamia the sloping socketed ax was usual (fig. 17), in Assyria the pickax (fig. 18). Not one of these was made by any Egyptian, and only two such were rarely brought in by Greeks in late times.

The principle of sockets for handles was well developed in Italy and spread elsewhere, for axes, hammers, and chisels, yet no Egyptian would make a socketed tool, and the only ones in Egypt were brought in by Greeks. The use of hammered sides to a blade, to form a flange for stiffening it, was of early date in Syria, and general in the north. Yet it is rare, and probably foreign, in Egypt, and unknown in the Mediterranean. The girdle knife (fig. 19) is common in the West and in Asia; the flamboyant-blade hunting knife (fig. 14) was usual in Italy, and spread into the North; the sword was the staple weapon in the North. Yet none of these were adopted by Egypt, and very few swords have been found there, nearly all foreign. In all these cases Egypt did not require a loan from the other lands.

This sharp separation between countries endured for thousands of years, while they were trading in food, materials, and manufacture continually. We can only conclude that each country already had, in these respects, what best suited it.

We now turn to the other historical point of view, the forms which are widely spread, because they were required. In Egypt at about



37 to 51.—Forms of tools alike in East or West.

52 to 60.—Four variants of Sicilian razor, separately adopted in the North.

5,500 B. C. there suddenly appeared a very large wide-splayed adz (fig. 38), different from all that came before or developed later. The

same large splayed adz (fig. 37) appears in Cyprus; it evidently came from there to Egypt, or both lands drew on a common source elsewhere. About 4,200 B. C. the ax with two large scallops in the back edge (fig. 40), leaving three points of attachment, suddenly appears in Egypt; a thousand years later it is far more advanced in Syria (fig. 39) than in Egypt, and it probably originated there, and spread also to Greece. About 3,000 B. C. a very strange drawing of a sickle appears in Egypt (fig. 42) unlike any other there; this is closely like a Swiss form (fig. 41). At the same time small daggers with notched tangs appear both in Switzerland (fig. 43) and in Cyprus (fig. 44). Here are links from the European copper age to the East. The same line of connection appears later, about 1,200 B. C., when the pruning hook (figs. 45, 46) from Noricum (the modern mines of Styria) appears in Egypt (fig. 47); the rhombic arrowhead of Greece and Italy is found also in Egypt, the bronze hoe of Cyprus (fig. 49) and Egypt (fig. 48) spread northward in the Iron Age, and the European sword was rarely brought into Egypt.

An interesting confirmation of history is seen in the knives with straight parallel blades and turned-over ends. These are characteristic of the Siculi in Sicily (fig. 51), and just at the time when the Shakal people were attacking Egypt the same knife (fig. 50) is figured in an Egyptian tomb, and a specimen also has been found. This proves the connection between the Siculi and Egypt at the time.

A curious evidence of different trade routes is given by the razor. An unusual form in Sicily has a concave hollow or notch in the end (figs. 52, 54), which was reduced to a mere split (fig. 56) or a slight hollow (fig. 59). The notch form traveled into Italy (fig. 55) by the simple way across the strait. The concave hollow, widened as a crescent, traveled up to Switzerland (fig. 53) and Germany (fig. 60), probably by the Adriatic. The split form (fig. 56) traveled to Flanders (fig. 58) and England (fig. 57), probably by the Rhone. Here four different modifications branch from a type and are carried by different routes to distant lands.

The triangular arrowhead is believed to have been started in south Russia. Thence it spread over central Europe and central Asia, and was taken by the Scythian migration into Syria about 600 B. C., and hence into Egypt.

Thus the spread of forms throughout the ancient world illustrates the movements of trade and of warfare, while the isolation of various types at the same time shows how efficient and self-supporting the ancient civilizations were in most requirements. The history of tools has yet to be studied by a far more complete collection of material, above all of specimens exactly dated from scientific excavations. It will certainly be, in the future, an important aid in tracing the growth and decay of civilizations, the natural history of man.

THE BACKGROUND OF TOTEMISM.¹

By E. WASHBURN HOPKINS,
Yale University.

The secret of the totem has been successfully veiled for many years through the ingenious efforts of would-be interpreters, some of whom have even ventured to explain all religion as an outgrowth of totemism. Others, less rash, have been content to find totemism where it never existed. A typical case of invented totemism may be seen in the Hindu deluge story, where Manu is rescued by a fish and the fish is interpreted as "probably a totem." This tale really illustrates the "grateful animal" category of folklore. A fish, saved by Manu, in turn saves him. It is a fish that grows too rapidly to be a normal fish, yet it is identified with the *jhasha*, of which genus the *makara* is the best species. Manu does not revere it; it is at first no divinity. Only long afterwards, when the chief god becomes Brahman, and again when Vishnu is exalted, does the fish become a divine form and Avatar.

The people of the Vedic age knew the boar, the wolf, the monkey, the swan or goose, the eagle, the crocodile, the serpent, and before its close the elephant, and the tiger, yet they worshiped none of them, nor showed any sign that they felt themselves akin to any one of these animals. It is true that sometimes a Vedic god is said to "rage like a terrible beast," but only a perverted intelligence could find in this statement evidence that the god had previously been the animal.² Divinity of real animals is borrowed afterwards from the wild tribes (who have totems) or is a later growth which recognizes divinity as in a cow because the cow gives food. The (cloud) cows of the air like the (lightning) snake of the sky may be ignored as due to poetic diction. So the fact that the sun is a bull, an eagle, a horse, is no indication that any one of the three was regarded *quâ* animal as a totem or even as divine.

Most attempts to find totemism where it is not remind one of the clever old Brahman who instructed Madam Blavatsky that all things were known to the seers of the Rig Veda. "Even the steam engine?"

¹ Reprinted by permission from the Journal of the American Oriental Society, vol. 38, pages 145-159.

² This is the absurdity to which Wundt is led, who says that because Homer's heroes are like lions therefore they are totemistic survivals (*Mythus und Religion*, 2, 285).

he was asked. "Certainly," he replied, "for, look you, in this place is mentioned smoke, here they speak of fire, and here again they sing of a car, and what is a locomotive save a car with fire and smoke?" So, to prove the existence of totemism, it is not enough to point to descent from a lion or to an individual name. In Africa clan-totemism often reverts to animal names given to one chief in flattery, "O thou elephant," "O thou lion among men."

Totem is said to mean "token," implying group relationship; but not blood relationship, since this would exclude plant totems, unless these are all secondary. But at present there is a tendency to deprive the word totem of every meaning it ever had. The totem of British Columbia is a protective spirit (often not animal) seen in a vision and has no relation to relationship; it is individual, not clannish. An African chief, on dying, said that he would become a butterfly. Straightway the butterfly became the "totem" of his clan (i. e., they would not kill it). And what shall we say of totems defined as "odds and ends" and "knots" (in Samoa), or the "heart of all animals" and "intestines" (African Kiziba "totems")? What is the use of calling these totemic phenomena? Each is simply a case of taboo; to one clan "intestines," *quâ* taboo, became sacred; but that is not a totem. So sex totems, honorific totems, color totems, cloud totems (Australian), twins as totems (Bantu Bahima)—are these totems at all? Or shall we say with Doctor Goldenweiser that, since every characteristic of totemism is negligible,¹ there remains as totemism nothing save a vague tendency for social groups to become associated "with objects and symbols of emotional value," and that totemism is merely a "specific socialization of emotional values"? Would not this tenuous definition apply to a Baptist church as well as to a totemic clan?

It may not be superfluous to remind the general student that totemism as the foundation of religion is only one of many suggested foundations, not one of which by itself will uphold the burden placed upon it. It was thought to be fundamental because it was said to be universal. But despite Robertson Smith's great work it has not been proved to be Semitic.² Nor has it been found among the Aryans, where even in the Lupercalia it cannot be discovered.³ In Africa what is called totemism is not religious and is usually derived

¹ The "invariable characteristics" of totemism are supposed to be exogamy, taboo, religious veneration (totem worship), name, and descent. But none of these is a necessary factor in totemism. Dr. River's "three essentials" are in typical form exogamy, descent, and taboo (of totem flesh), whereas totemism may exist without any of these characteristics and essentials. See "Totemism, an Analytical Study," by A. A. Goldenweiser, *Journal of American Folklore*, 23 (1910), p. 182, 266, 275.

² What Dr. Robertson Smith showed to exist among the Semites were elements of a possible totemism; but he could not show their combination. See his *Religion of the Semites*, p. 42 f. and 287; and (opposed) Lyall, in *JRAS*, 1904, p. 589.

³ See L. Deubner in the *Archiv für Religionswissenschaft*, 1910, p. 481 f. For other Aryan fields, see Saussaye, *The Religion of the Teutons*, p. 74, 98; and A. B. Keith, *JRAS*, 1907, p. 939.

from the personal totem.¹ In South America even Dr. Frazer admits that totemism and exogamy exist in only two tribes (the Goajiros and Arawaks, withal "almost surely," not quite), and the "mother sea" and "mother maize" of Peru were only ancestral food-givers (not totems). Moreover the admitted fact that the skin of the "lion ancestor" worn at festivals by the Chanchas is no evidence of totemism reacts on the explanation of such skin-clad revelers elsewhere, as in Greece and Rome.²

But by dint of calling almost anything totemism, totemism has been found almost everywhere. It really does exist in many different parts of the world, North America, Africa, Polynesia, Australia, etc. We will take it as we find it in some of its most primitive forms, where it has nothing to do necessarily with religion or with marriage.

In Australia, where we have been assured that there is no religion, only magic (but this is a fallacy), and where at any rate we find totemism without religious implication, there are two things to be considered. First, is this Australian culture unique or is it only part of a greater complex, taking in the Melanesians? Indications point to a common substratum rather than to isolation. How the connection arose is not difficult to imagine; why it stopped is harder to guess. At any rate there is the possibility that Australian savages represent not the most primitive stage but a decadent form of an earlier stage of culture, when, for example, these savages could sail the sea. Then, secondly, there is to be considered the complex of totemic groups. For the purpose of this paper I have stressed the kind of totemism in which the totem is eaten and exogamy is not considered. But no one kind of totemism can be posited for Australia. If totemism imply a relation (magical or religious) between a clan and a class of animals or plants, Australian totemism may be either in the female line (the child then belongs to the class of the mother), or in the male line (the child then belongs to the father's class of animals), the former sort being found more in the eastern part of the country, the latter in other parts. But the Australian group may be merely a fortuitous class of collective owners of a certain territory, and in this case the child belongs to its father's totemic class, but the group is not exogamous (a western sort of totemism). Besides these sorts there is the totemism of the cult society, in which all are totem members; the divided society, in which each half of the tribe has a different totem; and that of the four or eight divisions of relationship; while, in addition, sex-totemism again divides the tribe into two totemic parts. Moreover, per-

¹ See, for example, Ellis, *The Tshi-speaking Peoples*, etc., p. 205 f.; Nassau, *Fetichism in West Africa*, p. 210. Bantu totemism is usually of this sort. There is here no veneration for the totem.

² See Frazer, *Totemism*, p. 95; *The Golden Bough*, 2, 293; *Totemism and Exogamy*, 2, 230; 3, 571, 579.

sonal totemism (New South Wales) gives every individual a separate totem. In some of these there is a definite ritual; in some, no ritual at all or a negative ritual.¹

Australian custom has thus cast fresh light on totemism. But whereas in Australia reincarnation is associated with totemism and the guardian spirit is not associated with it, in British Columbia the guardian spirit is intimately associated with totemism and reincarnation is not associated with it. Moreover, descent from the totem is assumed in Australia and may be absent in British Columbia (it appears only in some tribes and then not clearly).

A very peculiar form of totemism has recently been found in the matrilinear society of the Fiji (a race probably connected with the Australians). There a man may eat his own clan totem, but may not eat his father's.² His own totem is derived from his mother. He may eat it, but his son may not. All the food growing on his father's tribal area (a sacred place) is taboo to the son, whether it be a banana or an eel, or both; to the son it is all "spirit food," taboo (but called "totemic"). As a converted Fiji Christian explained the matter:

Bananas and eels were forbidden to me by religious scruples because they belonged to my father. Formerly, if I ate them, they would make my mouth sore, but now that I have become a Methodist without any religious scruples, they do not hurt me.

This is "totemism" in terms of legal right to property. Anything growing or living on the paternal land is "totem;" i. e., taboo.

In northern Australia the majority of the tribes do not eat, or eat only sparingly, of the totem; but in some the mother's totem, if given by a member of the group, may be eaten. Here, too, it is a question of legal rights rather than a religious matter. In the Kakadu (northern Australian) form of totemism, the totem is determined by the spirit of a deceased person thought to be reincarnated in the totemist, and in this case there is no food restriction at all, simply because it is not a case of real totemism, since the spirit may come from any ancestor.³

It is evident that totemism raises the whole question of the fundamental relation between things secular and things religious in primitive mentality. Are they radically divided, is there a distinct

¹ Compare the paper of Mr. A. R. Brown at the Meeting of the British Association for the Advancement of Science, August, 1914, in which the different forms of Australian totemism are classified.

² Compare A. M. Hocrat, "The Dual Organization in Fiji," *Man*, 1915, no. 3. A man may eat his own clan animal ("dispose of his own"), "but he may not eat his father" (sic), because his father's is not his to dispose of.

³ Spirit children swarm about and enter women, as in the Central Australian Arunta belief. See Baldwin Spencer, *Tribes of the Northern Territory of Australia* (1914). On the connection between Australia and Melanesia, see Rivers, *History of Melanesian Society*. Apropos of possible ancestors in the New Hebrides a tribe traces its descent to a boomerang which became a woman ancestress of the clan.

cleavage between them, as is assumed in Durkheim's system, or shall we say that, as among the primitive Veddas, no such cleavage exists originally, but it develops gradually in accordance with the part played by religion in the social life? Conduct seems to have an accidental connection with religious life; not an intrinsic connection sufficient to produce a system of religious ethics. Even in the same race and clan totemic systems differ in regard to their social bearings.¹

Once it was supposed that totemism conditioned the bed and board of the totemist; he must marry out of his totem group (his kin) and he must not eat his totem except as a religious sacrament. On this assumption all the old theories of totemism were based. Exogamy, it was thought, arose from totemism.²

But as exogamy exists without totemism (e. g., in Assam and Polynesia), so totemism has nothing to do fundamentally with exogamy. "The Australian totemic clan is not as such exogamous."³ Again, the totemist may or may not eat his totem. The totem also as a "receptacle of life" of the totemist has been imagined to be exercising its primitive function; but this theory (of the origin of totemism) has also been seen to be faulty. The personal totem has influenced the aspect of totemism in America. Much of what is called totemism in Africa originates in personal, not tribal totems, though it may become tribal. In Coomassie, for example, vultures are sacred to the royal family either through the caprice of a ruler or because they are useful as scavengers.⁴ This is the kind of "totem" one finds as the totem of the royal house of Oudh in India, a fish that is really the symbol of a water god who was once a Mohammedan saint.

The totemism of the name is the prevailing Polynesian and Micronesian type and apparently it is there the earliest. Among the most primitive Micronesians there is nothing religious in the use of totem names or the plants and animals regarded as totems. It is to be observed also that here plants are as natural as animals in a totemic capacity. Since this is true also of primitive Australian totemism, it is evidently a false assumption that blood kinship underlies totemism, especially when the totem may be, e. g., lightning, as in Australia. In the Efatese (Micronesian) group, which is regarded as extremely primitive, women names are usually those of vegetables, and as the clan name is given by the ancestress there is really more vegetal than animal totemism.⁵ Both kinds are found,

¹ Compare B. Malinowski in *Man*, 1914, no. 89.

² J. F. McLennan, *Primitive Marriage*. A number of other works embody the same theory.

³ Goldenwelser, *op. cit.*, p. 241.

⁴ Ellis, *Tshi-speaking Peoples*, p. 213.

⁵ Compare D. MacDonald, *The Oceanic Languages*, p. xii.

however, and the point is chiefly that in the Efatese custom we have evidence of primitive totemism absolutely without reference to religion. The Efatese came perhaps from Arabia and may represent a primitive Semitic condition, where a purely economic and social matter became gradually overlaid with a religious coloring. So our Iroquois did not worship their totems, nor descend from their totems. Nor did the taboos of the Omahas have anything to do with their totems, and they also may descend from guardians. Even the name of the Omaha group is not that of the totem. Thus totemism is not a homogeneous institution. Under the appearance of uniformity it conceals a heterogeneous collection of social and religious conditions as vague and unsystematic as are those of taboo and fetishism. It consists, if it means anything specific, in clan respect for a class of plants or animals and usually in a regard for ancestors; but there is no proof that the most primitive totemism represents a condition in which these elements were already fused and confused, so that the plant or animal was the clan ancestor, whose descendants have human brothers who will not slay them. The clan worship of an inviolate totem is a late, not a primitive form. Originally, real totemism may or may not be religious; it starts with a certain relation to the source of food and is apt to end with food, but on its course it is obnoxious to all the ills of a diseased religious consciousness. The taboo of eating totem flesh is general in North America (though not universal), but such a taboo is not necessarily coterminous with the class; it may include a larger group, hence it may not be totemic in origin.

Certain aspects of totemism, such as tattooing and the use of totempoles and the "medicine" carried by totemists, may be omitted from the discussion of primitive totemism. So the various taboos incidental to totemism are results which in themselves do not explain totemism. A vital error is that the sacrifice of the totem is fundamental; this leads to the idea that all sacrifice is based on totemism. Lastly, there is a bookful of errors based on false notions of "original totemism" and to be avoided as idle speculations. One well-known writer has declared that all domestication of animals reverts to totemism; wild animals, finding that as totems they were not molested, came to man and became household pets; wolves became dogs, tigers became cats. So plants were cultivated first as totems until man discovered that maize was good to eat and tobacco to smoke! Wundt explains man's present dislike to a diet of vermin on the assumption that we have inherited the feeling that vermin are sacred ancestral totems. This incredible suggestion is made in all serious-

ness and is merely an instance of what imagination can suggest under the guise of science.¹

The name theory of totemism is an old error. Herbert Spencer derived totemism from names; Jevons derives names from totemism. Andrew Lang attempted to explain the totem as a name and part of a system of naming.² Something similar has also been tried by Pikler and Somló, who hold that the totem is a kind of writing—that is, that the totem animal, painted, served originally as a mark to distinguish one clan from another.³

Other theories refer totemism to a belief in metempsychosis or to a belief in a personal guardian spirit. The first was favored by E. B. Tylor; but as metempsychosis is held by non-totemic people and totemists do not all believe in metempsychosis, this theory does not suffice, though it applies to certain selected examples, like the Bantus. The guardian-spirit theory has been dubbed the American theory, because it was invented here⁴ and is illustrated by American tribes. Yet the fact that this type of totemism is lacking in many places; for example, among the wild tribes of India, where totemism is common, does not make for its acceptance as a general explanation of the phenomena. The phase is, in fact, not tribal but individual, and against the theory stands the circumstance that it excludes women, who have no personal totem. The guardian spirit (which may or may not be an animal-spirit) is in truth not a totem but rather resembles the bush soul. In higher form it becomes the genius and guardian angel.

Sir J. G. Frazer has advanced several theories in regard to the origin of totemism. He used to hold that the totem was the soul-keeper; but he then abandoned this view in favor of the theory that totemism was a system of magic intended to provide a supply of food for somebody else. This altruistic theory he explained as follows: In a group of clans every clan killed its own totem for some other clan and subsisted itself on the kill of a third clan. Clan A

¹ In his *Mythus und Religion*, 2, 298, Wundt thus explains by inherited "Gefühlston" man's otherwise inexplicable aversion to a diet of worms, mice, snakes, etc. What is true is that there is a common superstition to the effect that vermin represent the souls of demons or of evil persons (in India due to Karma; hence holy water keeps off noxious insects). Wundt of course derives all nature gods from animal gods. He ignores completely the cogent evidence to the contrary. In Churchill's *Weatherwords of Polynesia* (1907), men are derived direct from divine weather aspects, rain, clouds, etc., which, as gods, generate all the races of earth. The savages who thus invent gods of phenomena as ancestors can not be ignored; they represent a religious phase as primitive as totemism.

² *The Secret of the Totem* (1905).

³ "Der Ursprung des Totemismus," in the *Jahrbuch für Vergleichende Rechtswissenschaft*, 1902. On the deficiencies as well as advantage of the name theories, Wundt has some sound remarks, *op. cit.* 2, 265.

⁴ Miss Fletcher, *The Import of the Totem* (1895); Boas, in *U. S. National Museum* (1897). The personal guardian (seen in a dream) taken from the animal world is found also among the Iban of Borneo (originally from Sumatra). See *The Pagan Tribes of Borneo*, by Charles Hose and William McDougall (1912).

killed for Clan B, Clan B for Clan C, etc.¹ It is difficult to believe that savages, whose main business in life is to look out for number one, ever arranged their hope of a dinner on the precarious promise of some other clan to supply them with food; and in fact Dr. Frazer himself abandoned this *sic vos non vobis* theory in favor of still a third explanation, which he now thinks will be his last theory. At any rate, it is his latest, though we may venture to hope it will not be his last. It is based on the fact that some savages believe that their offspring comes not from intercourse between men and women, but from the spirits of animals or quasi-animals seen by a woman, or from the food she eats. They think that the spirits which thus become their children are really the animals they have seen or whose flesh they have eaten before conceiving. Hence Dr. Frazer calls this the conceptional theory.²

Curiously enough, almost all these theories absolutely ignore the usual foundation of totemism. The works of Spencer and Gillen on the tribes of central Australia have shown that here totemism generally reverts to the principle of food-utility. The so-called Opossums in central Australia received their totemic name because they "subsisted principally on this little animal."³ Is not this the most natural reason in the world? They that eat 'possum are called 'possums. They that eat meat in India are called Meaters. Do not we also have frog eaters, beef eaters, etc.? It is much to be regretted that Dr. Frazer in his latest theory has flung away completely all connection between food and totem, or admits it only as an accidental element in the conceptional theory. In fact, most totemism rests on food supply. The ancients tell us that the totemic troglodytes at the time of Agatharcides regarded their cattle as parents. Why? Because (they said) their cattle supplied them with food.⁴ In the Harivansha, which reflects Hindu belief of circa 400 A. D., the cowboys say:

The hills where we live and the cows whereby we live are our divinities; let the gods, if they will, make a feast to Indra; as for us, we hold the hills and cows to be the objects worthy of our worship and reverence. For in that

¹ The food theory of Dr. A. S. Haddon is that each clan subsisted on one animal and gave to its neighbors its superfluous supply; if crabs, then they would be called the Crab Clan.

² Compare *The Golden Bough* (1900), 3, 417 f.; *Totemism and Exogamy*, 4, 41 f. Dr. Frazer's latest theory is based on the investigations of Dr. W. H. R. Rivers, *Totemism in Polynesia and Melanesia*, *Journal of the Royal Anthropological Institute*, 1909, p. 172 f., in regard to the belief of the savages of Banks' Islands in the northern New Hebrides, especially the natives of Mota and Motlav. The conceptional idea itself is found, too, not only in Australia but in Germany, where also women were supposed to conceive on sight. On P. W. Schmidt's "trade totemism," *Z. f. E.*, 12 (1909), which follows the lines of Frazer's theory of food exchange, see Goldenweiser, p. 277.

³ Spencer and Gillen, *The Native Tribes of Central Australia*, p. 209.

⁴ Robertson Smith, *The Religion of the Semites*, p. 296.

they serve us they should be requited. That whereby one is supported should be his divinity; hence we will make a festival in honor of our cows.¹

This is exactly the Toda point of view, though not the Toda rite

The totemless Hindu here recognizes that the provider is the god to him provided for. This is the general background of "real totemism." It is found all over the earth and at times comes to the point of gliding into true totemism.

Thus, in Peru fish are deified on the seacoast and maize is not; but maize is deified inland, simply because it is the staple diet. This is the first step in totemization. The giver of food is the giver of life; the giver of life is conceived either as father and as mother or as both parents and god. Hence the maize is called not only divine but mother.

In the Boston statehouse there hangs to this day the effigy of a huge codfish, an object of almost devout reverence. Why? Because our Yankee ancestors got their food supply to a very great extent from this kind of fish. For that reason only was the cod elevated to a position of such dignity. They did not worship it, but they made it their "token." Their thought was "in Cod we trust," and they expressed this thought openly in the idol of that fish.

In Yezo a bear is sacrificed annually as a half-divine animal. It is fed and nourished by the women and then "sent to its parents" with every mark of sorrow and respect. Now this Yezo bear is not a totem. The Ainu claim no clan blood-brotherhood with it. Yet in this sacrifice we are at the very edge of true totemism; for the bear is the food supply, hence divine, hence too, sacrificed, that it may take a message to the bear clan, tell how well it has been treated, and return next year. Compare with this the spring sacrifice made by the Mayas of one animal of each species for the sake of getting increase. Are not these (which are not examples of totemism) almost totemistic? The Yezo ceremony is like that of the British Columbian Lillooet, who also sing a song of mourning to the bear they kill and invoke it to send game of its own kind. Even the raising of the head on a pole is found here.² Yet this is not a "totemic" clan.

But, it will be urged, why then the prohibition against eating the totem? In Australia the prohibition against eating is, as I have shown, a secondary stage, while in some cases there is merely a hygienic restriction. In America many tribes eat their totem, while

¹ Gāvo hi pūjyāh * * * goyajñam kārayisyāmi, Hariv., 2, 10, 1 f. (3807-3851). The cows are garlanded and sacrifice of meat and milk is made to the hills. It is grossly explained in the sequel that god Krishna "became the hill" (transubstantiation); but this is merely an orthodox trick to convert the rustic rite into one in honor of the recognized divinity.

² Teit, Jesup Expedition, apud Goldenweiser, op. cit., p. 204.

vegetable totems (maize, for example) are clearly sacred because they are a food supply. Sun supply and food supply in Australia brought forth the same rites. In other words, both rituals were for the same purpose, to increase the power of food giver and light giver as food giver. Nor can it be objected that "things not fit to eat" are made totems. Different times, different stomachs. Even our immediate forefathers ate things that we would rather revere than eat, and savages eat anything edible. Again, inedible things, such as poisonous objects, become holy by way of being hygienically taboo, and such a taboo plant, as holy, tends to confuse totem holiness with taboo holiness. In India there are many taboo trees and taboo plants, though none is a totem to the Aryan. They are taboo either because they are sacred to a god or because they are poisonous. So we have poisonous totems. The Begandas of Africa say that their whole totem system (it is not really totemism, but resembles it) is based on purely hygienic principles. Their "totem" is injurious; it made their ancestors ill; hence it is "holy"; hence not eaten. But others may eat it. Many other peoples permit their neighbors to kill the totem they themselves would like to kill and eat did they dare. The Australian Blackfellow now kills rarely what he used to kill and eat freely. Alabama and Georgia Indians always used to eat their totems. Is it not an assumption to say that these edible totems represent a later stage? Australian custom suggests that the non-edible totem is the later totem, the more edible the earlier. Moreover, worship is a secondary stage. The Omaha Indians never worshiped their totems. The Californians show a middle stage, that of the Egyptians and Todas, who kill but rarely and eat the totem as a sacrament. Then behind that lies the stage in which the totem is killed freely all the year round, but once a year is killed as a sacrament. Such is said to be the totemism found among some tribes of the Caucasus, and it is the usage, but without totemic kinship, of the Ainus already described. The animal killed is offered apologies lest its spirit retaliate; but this apologetic attitude is found with savages even when they kill an ordinary animal or cut down a tree. It is assumed merely to safeguard the slayer from its victim's angry spirit.¹

One plant and one animal in India have been divine for milleniums—the moon plant and the cow. Their deification as drink and food was gradual. At first anyone might drink the moon-plant beer and any guest had a cow killed for his food. The Soma then became reserved for the priest, the cow became reserved as milk giver. Both

¹ The apology to any animal slain is made in America; to the tree, for example, in Africa. It does not imply constant worship, but only a passing respectful solicitude, lest the animal or tree, being vexed, retaliate. This attitude results in a sort of momentary "worship" (placation).

became as food and drink divine; Soma as intoxicant became a magical thing, taboo to the vulgar. Yet neither Soma nor cow ever became a totem. Their divinity lay in their use not in their ancestorhood.¹

Wundt thinks he has added something to the history of totemism by saying that in establishing the totem on a cultural basis the cult itself was made permanent; in other words, periodic religious ceremonies leading up to an observance of days in general were introduced by totemism, which (in Wundt's own words) was "the greatest and most important step taken in the development of cult" (that is, of cult in general).² Yet this discovery of Wundt is not so significant as it appears to be. For it rests on the conviction that totemism is the base of all other cults. As a matter of fact, savages base their cult much more generally on seasonal changes than on totemic observances; in fact, the latter are often no more than the reflection of the former. Wundt with his overdriven theory of the Fanany-cult fails to recognize the equally old and far more common fear of animals not as totems but as spirit forms of reincarnated human beings. This popular belief is more important than that of the "worm spirit." On the whole, Wundt's theory that totemism underlies all religion and that, underlying totemism, is the belief that the worms crawling out of a dead man's body are his souls is as little likely to satisfy serious investigators as any of the one-sided theories of the origin of religion which preceded it. Not only is totemism not the basis of religion, it represents no religious stage or stratum whatever.³

If, then, we have regard to the fact that with all its divergencies in detail totemism in its original habitat (i. e., where the name arose) is in the main a recognition of a peculiar bond subsisting between a group of human and a group of animal or vegetable beings, that this bond is not an individual or sex matter, but that in the great majority of cases it is connected with dietary restrictions, we have the basis of what may reasonably be called totemism. To dub every cult of an animal totemic is like calling any object of religious regard a fetish; it tends to meaninglessness. From this point of view we may then reasonably admit as totemic what appears to be the earlier stage in this human bond, as illustrated by the cases forming what I have ventured to call the background of totemism, Australian, Peruvian, etc., in which the reason for the bond is palpably because the totem (though not yet a real totem) is regarded as the provider of sustenance, primarily because it is the totemist's food, Mother

¹ The divine myrobolan called "chebulic" as an efficacious drug arose from a drop of ambrosia; garlic sprang from drops shed by Rahu and has a demoniac power, etc. The Varuna tree is named for the god. Other plants and trees receive a similar sanctity.

² Wundt, op. cit. 2, 258.

³ See on this point the very sensible observations of Dr. Goldenweiser, op. cit.; p. 264.

Maize, Grandfather Fish, etc. Even where there is no tribal bond in the individual guardian this motive shows itself in another form, for the guardian is a spirit whose guardianship is especially exercised in leading the ward to his food, directing him on the hunt, just as the father ghost of the Vedda is invoked mainly to guide the suppliant son on the track of his prey.

If we abandon this guiding thread we are lost in the labyrinth. There remains no more than a vague notion that totemism indicates a social apprehension of some spiritual power, or, as a recent scientist has expressed it, "What is totemism anyway except consecration to spirits?" Nothing is gained by such a definition. On the other hand, it is a great gain to recognize that the old limitations imposed upon totemism are not essential; it does not necessarily imply worship, exogamy, descent, or name. All these things are special social variations springing out of totemism according to circumstances.¹

Thus, finally, the matter becomes a question of definition. Is it well to make totemism synonymous with any trait found in it? After all, the word totemism is American, and in America, until the sociologists began to play with it, it had a pretty definite meaning not necessarily involving name, descent, exogamy, worship, or taboo but always implying a clan connection with a class of animals or plants, and this connection ought to be maintained in our use of the word. That this connection was originally based on economic grounds (as I think) is a secondary matter. But we should not call lightning or intestines "totems." In an already established totemic environment such wierd "totems" may be adopted, as the social need of a totem may be satisfied by calling any object of taboo a totem, but secondary phenomena should not lead us to ignore what totemism really represents.

¹Among the Gilyaks a drowned clansman becomes a beast called Master (spirit), who is revered as a guardian. But this spirit lacks the fundamental essence of totemism in that it is (or was) human and individual. A half-human totem is a common Australian phenomenon, but always this monster is invented as an explanation of a bifurcated descent into animal and human categories; either the animal nature is always present, or the human ancestor has a very intimate connection with the totem animal. Association serves as well as descent in America to give the totem, but it is association with a non-human creature. In British Columbia, as in some of our tribes, the totem animal is a regular source of food supply and is freely hunted, killed, and eaten.

A GREAT NATURALIST—SIR JOSEPH HOOKER.¹

By SIR E. RAY LANKESTER, K. C. B., F. R. S.

It often happens in the progress of human thought that periods of special importance are marked, not, as rarely occurs, by the emergence of a solitary genius, but by the appearance of a group of gifted men of like habit of mind and enthusiasm for a given branch of study. Their coincidence in mental activity has been due sometimes to family connection and local association, sometimes to the system of universities in which a professor of genius is succeeded by his pupil and he again by his, so that a "school" originates which may spread its members and its teaching far and wide.

In the middle of the nineteenth century a group of naturalists appeared in this country who were destined to bring about a momentous change in human thought, by placing on a firm basis the doctrine of "organic evolution"—a doctrine which includes the gradual and "natural" development of living things from nonliving matter, and further the gradual and "natural" development of man from an animal ancestry. The group we have in view has Charles Lyell (born in 1797) as its starting point. Devoted from his earliest years to the study of natural history (his father being an accomplished botanist), Charles Lyell, when an undergraduate at Exeter College, Oxford, was attracted to geological study by the lectures of Canon Buckland. He was called to the bar, but fortunately his inherited property enabled him to abandon that profession when he was 30 years old, and to give all his energy to his favorite science.

In 1830-1832 Lyell published his memorable work entitled "The Principles of Geology: An Attempt to Explain the Former Changes of the Earth's Surface by Reference to Causes Now in Operation." That book and personal friendship with its author had a commanding influence upon two younger men, Charles Robert Darwin and Joseph Dalton Hooker, the former 12 years and the latter 20 years Lyell's junior. Darwin, who had studied geology with Sedgwick of Cambridge, was away on the voyage of the *Beagle* from 1831 to 1836, when Lyell's great book was published, but came immediately under its influence on his return, and in 1838 was closely associated,

¹ Reprinted by permission from the Quarterly Review, October, 1918.

as secretary of the Geological Society, with Lyell, for whom he conceived a profound admiration and lifelong regard.

Hooker left England in 1839, being then 22 years old, to accompany Captain (afterwards Sir) James Clark Ross, the experienced Arctic navigator, on the expedition of the *Erebus* and *Terror* to the Southern Hemisphere and Antarctic polar regions. The main purpose of this expedition was to make observations on terrestrial magnetism and to determine the position of the southern magnetic pole. But Ross was an ardent naturalist and anxious to observe and collect both plants and marine animals, and accordingly managed to take young Hooker as surgeon (he was M. D. of Glasgow) to the *Erebus* and botanist to the expedition. Ross not only gave his young surgeon every facility to collect plants in the various lands visited, but also employed him to work the towing net and make drawings of marine invertebrates when at sea. Some 60 years later a large portfolio of these beautiful and interesting drawings, which had never been published, were placed in the hands of the present writer by their venerable author, to ascertain whether, after so long an interval, they might have scientific value.

Young Hooker had Charles Darwin's example before him, and the recently published "Journal of a Naturalist on H. M. S. *Beagle*" in his cabin, when he sailed on the *Erebus*, but did not make Darwin's acquaintance until 1847, four years after his return from the Antarctic. Hooker's association with Lyell was earlier, for the Lyells of Kinnordy were intimate friends of his father; and it was from Sir Charles Lyell's father that he received the newly issued copy of Darwin's "Journal," just in time to take it with him to the Antarctic. With Charles Lyell's great book he had early familiarity, and he had also read Robert Chambers's *Vestiges of the Natural History of Creation*, which appeared in 1832. Though not a very convincing work, it turned his thoughts, with very definite results, to the question of the mutability of species—already raised by the essential nature of Lyell's geological doctrine and widely discussed at that time in consequence of the writings of Lamarck and St. Hilaire.

To this group of three (Lyell, Darwin, and Hooker), who were richly stored with knowledge of living things by their explorations in many parts of the globe, there was now added a fourth, T. H. Huxley. He made Hooker's acquaintance first at the British association meeting at Ipswich in 1851, having recently returned from the voyage of the surveying ship *Rattlesnake*, to which he had been appointed surgeon with a view to the opportunities thus provided of making studies in marine zoology. Old Sir John Richardson, the Arctic explorer, a first-rate naturalist and head of Haslar Hospital, whither in those days young naval surgeons were sent on probation,

had detected Huxley's abilities and secured for him the post on the *Rattlesnake* in 1847, just as eight years earlier he had used his influence to secure for Hooker a similar position on the *Erebus*.

These four men, Lyell, Darwin, Hooker, and Huxley, were the actual "begetters" and the chief propagators, both in the more restricted world of science and among the larger public, of the vivifying doctrine of organic evolution. The close personal ties which linked the first three were strengthened by the marriage of Joseph Hooker in August, 1851, to Frances Henslow, eldest daughter of the Cambridge professor of botany, the man who turned Charles Darwin to a scientific career. Huxley came to them, to use Hooker's own simile, "as steel to a magnet," and was soon admitted to the closest intimacy, giving them and receiving from them the warmest affection. A tie of fellowship between Hooker, Darwin, and Huxley was that they were all three "old salts" and had the training and "the knowledge of men" given by service in the royal navy. Huxley also met and sealed a close alliance with John Tyndall at the Ipswich gathering of the British association in 1851, and so brought that physical philosopher into close and permanent relationship with the Darwinian "nucleus." He, too, brought Herbert Spencer into constant relation with the group; whilst young John Lubbock (afterwards Lord Avebury), who was a neighbor of Darwin's, now settled at Down, in Kent, became, both by his scientific work in zoology, botany, and geology and by his personal charm, a welcome associate.

In 1864 Huxley, Hooker, George Busk (surgeon and naturalist), Spencer, and Tyndall, who had been close friends of Huxley's ever since his return from the voyage of the *Rattlesnake*, together with Frankland, the chemist, Hirst, the mathematician, old colleagues and allies of Tyndall, and Sir John Lubbock and Spottiswoode, friends of them all, founded the "X Club," which met once a month for dinner, its purpose being, as Mr. Leonard Huxley tells us—

to afford a definite meeting point for a few friends who were in danger of drifting apart in the flood of busy lives. But it was in itself a representative group of scientific men destined to play a large part in the history of science. Five of them (there were nine in all) received the Royal medal of the Royal Society; three the Copley medal, the highest scientific award; one, the Rumford; six were presidents of the British Association, three were Associates of the Institute of France; and from amongst them the Royal Society chose a secretary, a foreign secretary, a treasurer, and three successive presidents. * * * They included representatives of half a dozen branches of science—mathematics, physics, philosophy, chemistry, botany, and biology; and all were animated by similar ideas of the high function of science and of the great Society which should be the chief representative of science in this country.

Not unnaturally the club exercised, during its 28 years of existence (it expired in 1892, owing to the dispersal of its original members and the decision not to elect new ones), a great influence on the prog-

ress of scientific organization, an influence which assuredly was not sectarian nor exercised for party purposes. While the club, though bound up with the Darwinian movement, did not comprise the originators of that new doctrine, Lyell and Darwin himself—on account of their health and absorption in special pursuits at a distance from the town—it also, for a similar reason, did not include Alfred Russel Wallace, who had lately returned to England from his long sojourn in the tropics. His name can never be forgotten as that of one who, independently of Darwin and while exploring in the tropics, conceived and stated the identical theory of the origin of species by the natural selection of favored varieties in “the struggle for existence,” which had been more fully worked out, though held back from publication, by the elder naturalist. Wallace, as all the world knows, gladly gave all credit in the matter to Darwin, and contributed by his original observations and arguments, and by the lucid exposition given in a series of invaluable books for a period of more than forty years, to the establishment of Darwin’s doctrine of organic evolution. Wallace held himself very much aloof from the London whirlpool, finding happiness and full occupation for his long life in scientific work.

It is perhaps a mere coincidence, but in any case a very important fact, that we have a series of remarkable volumes giving in an unusually complete form the Life and Letters of Lyell, of Darwin, and of Huxley. Happily they wrote many letters, fortunately preserved for publication, in which their scientific work and the development of their views, as well as delightful revelations of character, of their tastes, their likes and dislikes, and of their heroic struggles and daily occupations, are recorded. These volumes can perhaps hardly be called “biographies”; they are the materials for considered well-balanced biography. They have been gathered by loving hands and connected by a thread of narrative and explanatory notes. Now we have a similar Life and Letters of Hooker, the material for which has been arranged by his widow, and presented in due order by Mr. Leonard Huxley, who had already done for his father’s memory what he has here, with skill and experience, done for that of his father’s closest friend. The letters here given, taken with those of Darwin and Huxley and Lyell, interweave with and complete one another, giving a remarkably close picture of the growth of a great scientific theory.

We have indicated in bald outline the place which Hooker occupied in the little group of naturalists who established, in the later half of the nineteenth century, the doctrine of organic evolution. Since we are here concerned with the story of his life and work, it is now time to state more specifically what was his actual contribution to the science of his time, and then to point out, as these volumes of

his "Life and Letters" enable us to do, to what native gifts of mind and character, on the one hand, and to what fortunate circumstances of training and association on the other, this contribution was due. Those are the inquiries which must always be of foremost interest when we are in possession of the detailed story of a great man's life.

Hooker was before and beyond everything else, a great botanist, the greatest "knower" of plants of his day, whether we estimate the immense number and variety of plants which he knew, or the thoroughness of that knowledge, or the vast area—that of the whole earth's surface—the vegetable population of which became familiar to him, either in the dried collections of travelers or (to an extent never achieved by any earlier or contemporary botanist) in their living condition. The latter result was attained in two distinct ways: Firstly, by his prolonged and often perilous journeys to the Southern Hemisphere, to India and the Himalayan region, to Palestine and the Lebanon, to the Atlas Mountains and to North America; and secondly, by his control of the most extensive and admirably organized botanic garden in the world, where living plants were almost daily received or were raised from seed sent from every part of the earth's surface.

Probably the greatest permanent benefit conferred on mankind by Hooker—his greatest contribution to science—was his organization, as a great and permanent state institution, of the gardens, plantations, glass houses, museums, laboratories, and the incomparable herbarium, at Kew, together with its highly trained staff of all grades, its splendid and continuous series of publications, its world-wide correspondence and close relations with botanical institutions in the colonies and India, so as to form a vast living mechanism, working under his incessant care for the increase of botanical science. The indifference, the opposition, the sheer brutality, by which his efforts were too frequently opposed, and the ultimate triumph by which his tenacity of purpose, his honesty and unworldliness of character, were rewarded, can be realized and appreciated by the reader of this book. So also can one learn with pleasure of the fine men, both among his scientific colleagues and the few intelligent officials with whom he had to deal, who sympathized with and helped him.

Here we may read the full story of the ignorant insolence of one Ayrton—an obscure politician who became a minister of the Crown, and proposed to make Kew into a mere pleasure garden and to give his orders to Hooker as to a head-gardener, but was, by a timely rally of wiser statesmen and lovers of science, brought to heel like a whipped dog. Here, too, we read of the mean financial tricks of the East India Co.; the delays of the Admiralty; the stupid parsimony of the Treasury relieved by the generosity and friend-

ship of Lord Dalhousie, the Governor-general of India; the goodwill of fine old Admirals; and the enthusiasm of many high-placed officials (such as Bertram Mitford, Lord Redesdale), and well-tried friends who valued pure science and were spell-bound by Hooker's abilities, persistence, freedom from all desire for personal profit, and simple-minded devotion to one noble end—the building up of what were for him two inseparables, Kew and Botanical Science.

Hooker's more direct contributions to scientific botany are parallel in importance to the creation of the great institution (founded by his father and completed by the loyal help of his son-in-law and successor, Sir William Thiselton Dyer), wherein he worked out during many years the enormous collections of plants brought thither by himself and amplified by official and private collections. His first scientific paper, on some new mosses, was written and published in 1837, when he was only 20 years of age; his last in 1911, on some Indian species of the balsams (genus: *Impatiens*)—a large and difficult group to which he gave minute study, dissecting them under the microscope and drawing them with all the skill and assiduity of his youth, until within a few days of his death in his ninety-fifth year. The mere titles of the papers and volumes which Hooker produced in those 74 years of work occupy 20 pages in the "Life." No mere enumeration of their number can give an idea of their bulk, of the number of drawings and often colored pictures which illustrate them, of the tireless industry which produced them, or of their scientific weight and purpose.

For the convenience of ready publication he carried on throughout his life (with the assistance in later years of other botanists, his chosen colleagues) Hooker's *Icones Plantarum*, founded by his father in 1837, and the *Botanical Magazine*, founded by William Curtis in 1787, which has appeared regularly every month during 130 years. It was edited for 40 years by Sir William Hooker, on whose death in 1865 Sir Joseph became editor and chief contributor, handing it over in 1904 to his successor as director of Kew, Sir William Thiselton Dyer. For 78 years the two Fitches, uncle and nephew, were the only artists (without rivals for the perfection of their work) employed on the production of the hundreds of plates picturing new or rare plants published in the *Botanical Magazine*. But Hooker's greatest works were published as separate volumes, usually by the aid of grants from government departments. Such were the *Flora Antarctica* (1844–1847), 2 volumes, with 198 plates; the *Flora Novæ Zelandiæ* (1853–1855), with 130 plates; the *Flora Tasmaniæ*, with 200 plates; and the *Flora of British India* (by J. D. H. assisted by various botanists), 1872–1897, 7 volumes. A great number of important papers of smaller bulk,

but always of special significance, were published by him in the Transactions of the Linnæan Society, in the journal of the Geographical Society and other journals, and as contributions to the works of other authorities, British and foreign.

Hooker did a vast amount of work with his own hands, his own pencil and pen. The mechanical work of sorting the "hay-stacks," as collections of dried plants are irreverently called, the selection of specimens for description and incorporation in the herbarium and of duplicates for distribution to other botanical institutions and individuals (a proceeding by which exchanges were obtained and the completeness of the Kew herbarium assured), was always a delight to him; the mechanical labor and the mere "handling" of plants being, as he tells us, a relief from closer work and yet conducive to thought and reflection bearing on his one great purpose. Of course, he had an efficient staff and distinguished botanists as volunteer assistants, attracted by the unique conveniences for study afforded by the great herbarium, the library and the working-rooms, for which by degrees, following out and developing the cherished scheme of his father, he succeeded in getting the reluctant officials of the Treasury and the Board of Works to disburse the necessary funds.

The great interest for Hooker in all this accumulation of knowledge touching the flora of every part of the world, over and above the mere record of new plants and their habitat, was the discovery of the causes which have led to the present geographical distribution of plants. The problem continually presented itself to him in his travels. Take, for instance, the following passage in a letter written to his father from the Thibet frontier in 1848:

To-day I went up the flanks of Donkiah to 19,300 feet * * * The mountains, especially Kinchin-jhow, are beyond all description beautiful; from whichever side you view this latter mountain, it is a castle of pure blue glacier ice, 4,000 feet high and 6 or 8 miles long. I do wish I were not the only person who has ever seen it or dwelt among its wonders * * * I was greatly pleased with finding my most Antarctic plant, *Lecanora miniata*, at the top of the pass; and to-day I saw stony hills at 19,000 feet stained wholly orange-red with it, exactly as the rocks of Cockburn Island were in 64° south. Is not this most curious and interesting? To find the identical plant forming the only vegetation at the two extreme limits of vegetable life is always interesting; but to find it absolutely in both instances painting a landscape so as to render its color conspicuous in each case 5 miles off, is wonderful.

How does it come about that this plant flourishes in two such widely remote regions? How can we account for hundreds of other instances of the presence of identical plants in isolated localities thousands of miles apart, and for the absence of others in regions contiguous with one in which they abound?

The great botanists preceding Hooker had believed in the "special creation" of this endless variety of species and widely differing grades and elaboration of vegetable life, as an ultimate fact. Buffon, at the end of the eighteenth century, had pointed out the connection of climate with the distribution of plants, and argued that vegetation must have commenced where the cooling globe was first cold enough to support it,—i. e., at a pole. He remarks that "the same temperature might have been expected, all other circumstances being equal, to produce the same beings in different parts of the globe both in the animal and vegetable kingdoms." To him also we owe the recognition of the limitation of groups of species to regions separated from one another by "natural barriers." Tournefort had, still earlier, pointed out the likeness between the vegetation of successive elevations, implying successive reduction of temperature, and that of successive degrees of latitude carrying the same successive change of climatic condition. Humboldt (whom Hooker met in Paris in 1845) showed that many great natural orders of plants (Gramineae, Leguminosae, Compositae, etc.) are subject to certain laws of increase or decrease relatively to other plants in going polewards (in both hemispheres) and skywards. The construction of the "isothermals" of the globe, which we owe to Humboldt, was a great instrument toward the advancement of geographical botany. Hooker regarded him (as he says in a letter to Darwin in 1881) as the greatest of scientific travelers; and in 1845 he writes of him (vol. i, p. 185):

He was never tired of coming to ask me questions about my voyages [the Antarctic expedition with Ross]; he certainly is still a most wonderful man, with a sagacity and memory and capability for generalizing that are quite marvelous.

Lyell had shown that distribution is not a thing of the present only or of the present condition of climates and present outline and contours of lands. He also showed that our continents and oceans had experienced great changes of surface and climate since the introduction of the existing assemblages of plants and animals; that there had been a glacial period, and long before that a warm Arctic period, as proved by the abundant fossils (brought back by Arctic travelers) of plants belonging to a warm temperate zone. But these relations of flora and climate were looked upon as the outcome of direct adaptation by sudden and inexplicable acts of creation. It was Hooker's special merit and privilege to be the first to introduce into the attempt to explain the facts of the geographical distribution of plants, the conceptions already current in the scientific world of (a) the *mutability* and derivative origin of species; and (b) the *migration* of floras. This he did independently, by his own "self-thought," as Darwin termed it. His views are apparent in his earlier

publications, but are most fully set forth in his *Introductory Essay to the Flora Tasmaniae*, dealing with the Antarctic flora as a whole.

His study of Darwin's plants from the Galapagos Islands and their relation to those of other tropical islands and of the South American Continent brought him into close relation with Darwin, whom he visited in 1847. This was the beginning of their memorable intimacy and continuous exchange of letters (contained in these volumes and the similar *Life and Letters of Darwin*). These letters were really conversations as to endless botanical details—inquiries made and answered, criticisms and arguments submitted by one to the other. They form a record of surpassing interest to all future generations of biologists. Hooker's stores of knowledge of fact in every department of botanical science were of essential service to Darwin, while Darwin's marvelous fecundity in original suggestions as to the explanation and the significance of facts and his remorseless criticism of those suggestions by appeal to other facts and to experiment, were a perennial stimulus to Hooker, who was himself a theorist, a generalizer—what is sometimes called “a philosopher”—of large outlook. Lyell wrote in 1859 to Hooker of the *Introductory Essay to the Flora Tasmaniae*:

I have just finished the reading of your splendid *Essay on the Origin of Species*, as illustrated by your wide botanical experience, and think it goes far to raise the variety making hypothesis to the rank of a theory, as accounting for the manner in which new species enter the world.

And Darwin wrote:

I have finished your essay. To my judgment it is by far the grandest and most interesting essay on subjects of the nature discussed I have ever read.

Hooker was the earliest prominent naturalist to declare his adhesion to the theory of the *Origin of Species* by Natural Selection set forth by Darwin in his historic volume of 1859, but his complete adhesion to it was only arrived at by long and minute discussion with Darwin of his data, his arguments, and inferences, extending over some years both before and after 1859, in which the two naturalists were in constant communication. It must be borne in mind that Darwin's theory of the survival of favored varieties by natural selection was something additional to the hypothesis of the derivative origin of species which Hooker had supported. Darwin's theory gave an explanation of that derivation, and showed it to be the necessary result of existing natural causes.

Hooker continued during the next 22 years to take a leading part in the development of an understanding of the geographical distribution of organisms on the earth's surface in the light of Darwin's great doctrine of natural selection. He was at times much perplexed by the attempt to demarcate natural phyto-geographical provinces and subprovinces, as distinct from merely topographical

areas; and, finally, he seems to have come to the same conclusion as that which he reached in the classification of the vegetable kingdom adopted by him in the monumental work which he produced in collaboration with Bentham, the "Genera Plantarum" (3 vols., octavo, 1862-1883). This conclusion was that, while we are still seeking a closer knowledge of the phyletic connections of the floras and faunas of the world, it is, in view of *practical* purposes (that is to say, for facilitating the accumulation and orderly arrangement of our knowledge), better to adopt a frankly arbitrary series of groups and provinces agreed upon and accepted because they are traditional and serviceable for purposes of reference, than to assume prematurely that we are in a position to define the limits and connections of all natural phyto-geographical provinces and of all phyletic groups. To do this we have not yet (he thought) sufficient knowledge, though we already see clearly much of the outlines and the needful lines of inquiry.

The means and the causes of the migration of plants were matters of extreme importance in the great problem of distribution and the closely connected problem of the changes of land and water on the earth's surface. These were the subject of speculation and inquiry by both Darwin and Hooker. Hooker had at first put forward the hypothesis of a lost circumpolar continent in order to account for the facts of plant distribution in the southern hemisphere. But Darwin favored the view of the persistence even from Silurian times of the great continental masses at present existing, and the radiation from the northern temperate and subarctic region of successive floras by spreading along the cold mountain chains which extend through the tongue-like southward projections of continental land—to-day traceable as South America, Africa, and Indo-Malaya. Transport of seeds, etc., by ocean currents, by wind, and by birds and other such agencies was shown experimentally by Darwin to be possible in many cases, but the emergence and submergence of large tracts of land as bridges or connections across the deep ocean beds were rejected by him. Hooker writes to Darwin in 1881:

Were you not the first to insist on this [the permanence since the Silurian period of the present continents and oceans], or at least to point this out? Do you not think that Wallace's summing up of the proof of it is good? I know I once disputed the doctrine or rather could not take it in; but let that pass. (Vol. II, p. 224.)

He goes on to say, in reference to the address which he was preparing for the British association meeting at York, in which after many years' labor he expressed his final conclusions on geographical distribution:

I must wind up with the doctrine of general distribution being primarily from north to south with no similar general flow from south to north—thus support-

ing the doctrine which has its last expression in Dyer's essay read before the geograph. society and referred to in my last R. S. address (1879).

The conclusions at present held on this great subject, which so long occupied Hooker's attention as well as that of his friends Darwin and Wallace, are fully and admirably stated by Hooker's son-in-law and successor at Kew in his article on the "Distribution of Plants" in the last edition of the *Encyclopædia Britannica*—an essay which permanently associates the name of Sir William Thiselton Dyer with those of Hooker and Darwin as a great master in this many-sided field of scientific speculation.

While Hooker never ceased to carry on by his own individual work and that of his staff the preparation and publication of systematic "floras" of all parts of the British Empire, with a view to a full understanding of the origin of species and their geographical distribution (perhaps we should reverse the order of those terms), his botanical work was by no means limited to this. The "*Life*" gives a full picture of his activities, which we may briefly summarize by mentioning some of his publications, while his letters, there reproduced, to his father, to Lyell, Darwin, Harvey (of Dublin), Bentham, Bryan Hodgson, Asa Gray, Huxley, Paget, and a host of other friends and fellow-workers, reveal the methods of his scientific work as well as his aims and struggles, the steps of his official and public career, and his family life. From them, too, we can gather his views not only on scientific problems, but on art, literature, politics, education, and religion.

From the long list of his works (other than those already cited) we select first that on *The Rhododendrons of Sikkim-Himalaya* (1849-1851), edited by his father from material sent home by him while he was away collecting, drawing and mapping in the Himalayas. It is a sample of the beauty of form and color which entrances the true naturalist, however austere may be his devotion (as was Hooker's) to pure science. He writes:

It is a far grander and better book than even I expected. * * * All the Indian world is in love with my *Rhododendron* book.

Then we have his *Himalayan Journals; or Notes of a Naturalist in Bengal, the Sikkim and Nepal Himalayas, the Khasia Mountains, etc.*, (1854, reissued 1905), a book like Darwin's *Voyage of the Beagle* and Wallace's *Malay Archipelago* for all to read and enjoy; his *Students' Flora of the British Islands* (1870), which has run through three editions; and his *Primer of Botany* (1876), which has been reprinted 20 times in three editions—"the rashest and most profitable of all my undertakings," as he called it in a letter to Asa Gray. His paper "*On the Diatomaceous Vegetation of the Antarctic Ocean*"

(Brit. Assoc. Reports, 1847), was the forerunner of that study of oceanic deposits which many years later became (especially in connection with the voyage of the *Challenger* a great and important branch of research. Similarly his papers on *Stigmaria* and *Lepidostrophi* in the memoirs of the Geological Survey, 1848, were the starting point of the study of the tissues of ancient fossil plants by means of the microscope. He was the first to have sections of fossils cut sufficiently transparent for that purpose, a method which in the hands of a later generation has yielded very important results.

In the domain of physiology, besides some other contributions, there stands out his remarkable work on the attraction, capture, and digestion of insects by the pitcher plants (Brit. Assoc. Reports, Belfast, 1874, and "Nature," 1870). The work was suggested by Darwin when investigating the carnivorous habits of the sundew (*Drosera*.) Experiments as to the digestive ferment and microscopical investigation of the glands, etc., were made by Hooker, aided by Dyer, at Kew. In the special study and exploration of remarkable morphological characters, Hooker's investigation of the root parasites known as *Balanophoreae*—curiously simple in structure, without leaves or petals—formerly thought to be allied to the fungi, but shown by Hooker to be degenerate mistletoes, is a sample of his morphological work (On the Structure and Affinities of the *Balanophoreae*, Linnean Society Transactions, 1856). He made acquaintance with these strange plants both in New Zealand and in the Himalayas.

But the most striking thing which he did in this way was his description of the morphology, development and histology, and the determination of the affinities of a weird-looking South African plant discovered by Dr. Welwitsch in dry country inland from Walfisch Bay, and sent by him to Kew. Hooker named it after its discoverer; and specimens of it (since received through other travelers) have been kept in cultivation ever since in one of the hothouses at Kew (On *Welwitschia*, a new Genus of *Gnetaceae*, Trans. Linn. Soc., 1863). Hooker's triumph in this investigation was that of showing, by microscopic examination of the tissues and of the reproductive structures and their development, that this strange-looking plant is one of the *Gnetaceae*, a family including the little European *Ephedra* and grouped with the Cycads, the Ginkgo trees, and the Conifers in the great assemblage called *Gymnosperms*. In the Life and Letters we have a delightful picture (which will stir the sympathy of every morphologist) of his excitement, his hard work with the microscope, his reasoning, his results, and the reaction that followed. He writes (Jan. 20, 1862), to Huxley—

This blessed angola plant has proved even more wonderful than I expected—*figurez vous* a Dicotyledonous embryo, expanding like a dream into a huge broad woody brown disk, eight years old and of texture and surface like an overdone loaf, 5 feet diam. by 1½ high above the ground, and never growing higher, and whose two *cotyledons* become the two and only two leaves the plant ever has, and these each a good fathom long. From the edges of this disk above the two leaves, rise branched annual panicles, bearing cones something like pine cones, which contain either all female flowers, or all hermaphrodite flowers; the hermaphrodite flowers consist of one naked ovule absolutely the same as of Ephedra, in the organic axis of the flower, surrounded by six stamens and a four-leaved perigone. The female flower is quite different.

Lastly, fancy my joy at discovering the key to the development of this hypertrophical embryo taking to become a plant after the fashion it does; and at my being able to show that * * * it is undoubtedly a member of the family Gnetaceae amongst Gymnosperms, as the structure of the ovule and development of the seed and embryo clearly show. It is out of all question the most wonderful plant ever brought to this country—and the very ugliest. It reopens the whole question of Gymnosperms as a class, and will (in the eyes of most) raise these, as I always said they would be raised, to equivalence in these respects with Angiosperms.

At this moment he was fortunate enough to receive five splendid specimens from a Mr. Monteiro, of Loanda, who “like a trump” sent down the coast at his request to get them. Much help, he says, was given by one of his staff, Professor Oliver, who had been examining the tissues where he had left off, making “some charming drawings that will save me a world of trouble.” The completed monograph was read at the Linneæan Society in December, 1862, and published in the “Transactions.” The reaction after a heavy and exciting piece of work set in, as so many ardent investigators know it has a way of doing. When it was finished he wrote to Darwin:

My wife went to Cambridge and enjoyed it; I stayed at home (and enjoyed it), working away at “Welwitschia” every day and almost every night. I entirely agree with you, by the way, that after long working at a subject, and after making something of it, one invariably finds that it all seems dull, flat, stale, and unprofitable. This feeling, however, you will observe, only comes (most mercifully) after you really have made out something worth knowing. I feel as if everybody must know more of Welwitschia than I do, and yet I can not but believe I have, ill or well, expounded and faithfully recorded a heap of the most curious facts regarding a single plant that have been brought to light for many years. The whole thing is, however, a dry record of singular structures, and sinks down to the level of the dullest descriptive account of dead matter beside your jolly dancing facts anent orchid-life and bee-life. I have looked at an orchid or two since reading the orchid book, and feel that I could never have made out one of your points, even had I limitless leisure, zeal and material. I am a dull dog, a very dull dog. I may content myself with the per contra reflection that you could not (be dull enough to) write a “Genera Plantarum” which is just what I am best fitted for. I feel that I have a call that way and you the other.

A splendid and illuminating revelation of a generous and too modest character.

As a concluding item in our necessarily incomplete but representative selection from the long list of Hooker's varied work in and for science, we must cite his action when president of the Royal Society in 1878 in raising a fund of £10,000 (chiefly by subscription from wealthy friends of his own among the Fellows of the Society), by which new Fellows were relieved of the large entrance fee and all were in future to pay a reduced annual subscription of only £3. This admirable measure, entirely due to Hooker's initiative, had the result that, as Mr. Leonard Huxley writes, "no man henceforth need be kept outside the society on the score of money." Of the many services in economic botany, which under his direction Kew rendered and continues to render to distant parts of the Empire, we have no space to say more than that they comprise the introduction from South America to India of the quinine plant, and of the rubber tree (*Hevea*), and the scientific supervision of the cultivation in the West Indies of the neglected sources of wealth—the sugar cane, tobacco, and Jamaica oranges.

When we examine, as the Life and Letters and our own observation of him enable us to do, the personal qualities which carried Hooker through his exceptionally long life with such splendid success, such unflinching spirit and contentment, and such lasting benefit to humanity (he was, we learn, selected by the Japanese, soon after his death, as "one of the 29 heroes of the world that modern time has produced"), we find that the emergence of those qualities was not due to heredity alone, but largely to the training which they received from a gifted and affectionate father, for whom he had profound sympathy and filial devotion. Hooker was born with a vigorous constitution and great physical endurance. He had an inborn tenacity of purpose and single-minded attitude to life, and was as remarkable for his frank honesty as for his courage. He inherited from his father and his maternal grandfather (both botanists) his aptitude for botanical science, but it was the teaching and example of his father which, from his earliest years, trained and developed that aptitude. He modestly but with characteristic insight said of himself when at the age of 70 he received the Copley medal of the Royal Society, that he had no genius, no exceptional powers or exceptional talent, but that he possessed that inward motive power—some heat, some fervor, which compels us to exercise our faculties and to ripen the fruits of our labors—which he would call "the wish to do well," expressed in the modest motto chosen for himself 400 years ago by Prince Henry the Navigator, "*Talent de bien faire.*"

His constant association, from boyhood onwards, with his father in the garden and herbarium created by the latter in Glasgow after his appointment as professor, made botany a part of his very existence. At the same time the aptitude for it must have been born in him. It was not inherited by his elder brother, William, who, having the same opportunities, showed no liking for the subject, and, though more vivacious than his younger brother, displayed no scientific bent. From this point of view it is interesting to note that not one of Joseph Hooker's six sons has been attracted by botany or by scientific research. Sir William Hooker, a man of distinction in science and of influence in the official world, was able to communicate to his son his own tastes and ambitions, and to secure for him that early official employment which started him on his career as an investigator and established him for life in the great center of botanical science created by Sir William.

The intimate association of father and son, and the complete devotion of the younger man to the development of the elder's cherished projects, find a parallel in the life work of Alexander Agassiz, who realized, on a magnificent scale, the plans for a great museum and institution of zoological research at Cambridge, Massachusetts, designed by his father Louis Agassiz, but only in part carried into execution. Alexander Agassiz, as a young man, deliberately set to work as a mining engineer in order to procure that pecuniary independence which he decided to be necessary in the United States for one who wished to become a great zoologist. Before he was 30 years of age a copper mine in Michigan made him a millionaire and stood to him in the place of the official income and vast state supported apparatus which awaited Joseph Hooker at Kew. Both men became great leaders in their science, and, in greatly developing and completing their fathers' work, left splendid monuments of their heritage and their devotion. It is interesting to note that the sons of Alexander Agassiz, like those of Joseph Hooker, though always on terms of affectionate intimacy with their father, have not become "men of science."

Hooker frequently acted in younger days, as examiner in botany for various boards and universities. He was a member of the senate of the University of London. Some valuable records of his views on education, which deserve special consideration at this critical moment, are to be found in these volumes. His views are of especial value because he was, above all things, a practical man, seeing his aim clearly and bringing his trained judgment and vast experience of men to bear on the means to be pursued in order to attain it. He was also absolutely frank and fearless in the expression of his conclusions. We quote below ("Life," vol. ii, p. 329) a letter of his

to his friend the Rev. J. D. La Touche, dated May 24, 1893. He says:

You must not think that I oppose education of the laboring classes, but I should like it conducted toward the future life of the average, and not to the high education of the few who can profit by the complex education of the board schools. Mind you, I am just as much against the higher school and college education of the masses of the upper classes. Surely it would be far better if much of their teaching were devoted to making them more useful members of society. * * * To return to technical education, my notion of it is that it should be begun early, at the expense of some of the board's literature, classical English, etc., and be accompanied throughout by semi-scientific teaching; i. e., the cobbler should be taught what tanning is, what bristles are, and how developed, and so forth. If any board school child shows a genius for the higher education, push him on by all means to school and college; but it is no use trying to "make silk purses out of sows' ears."

From his earliest days onwards, Hooker shrank from public speaking; he disliked lecturing, and never held a professorial post. He detested newspaper discussions as well as the pomps and vanities of official ceremony. They all seemed to him as using up the time and strength which he ought to give to his one purpose—the increase of science. His natural and strong determination was to the most thorough and strenuous work in pure scientific investigation. He desired no popularity, but cared only for intimacy with and approval by the select few who were able to participate in his scientific work and thought, or were bound to him by long association. He was a man of the family, not a man of society. Nevertheless his long life, his high position, and wide-reaching activities brought to him a vast number of acquaintances, inspired by admiration and affection for his kindly, frank, and energetic character. With his children and numerous family connections he found relaxation and refreshment in music and dancing and in reading works of fiction and romance. He became an enthusiastic admirer and collector of Wedgwood ware, and fully indulged in the collector's joy of picking up good pieces in the shops of second-hand dealers. He retained from early life the habit of constant, regular, and uninterrupted work, and the simplest tastes in regard to food. He attributed his long life and the preservation of his health and mental power (as he said to the writer, who visited him on his ninetieth birthday) to the fact that he had made it his practice throughout his life to dine in the middle of the day, drinking only a light wine, and to take nothing but a light tea in the evening.

Hooker was, it is true, fortunate in his friends—fortunate because he merited such fortune. We read in these volumes of their passing away one by one—until he at last was left alone, but not downcast. His mind, to the end, was full of happy memories, and he still had new plants to describe and was tended by his wife and interested

in his garden. His long and fraternal association with Darwin was of vital importance to each of them. The genius and originality of his friend fed, as it were, on Hooker's immense stores of botanical knowledge; and Hooker, in turn, was stimulated by Darwin's inquiries into new lines of activity and acquired, in aiding his friend in those inquiries, a convincing proof of the decisive value of his own vast labors in building up the knowledge of plants. The *Life and Letters* form a fascinating record of that romantic, well-nigh legendary period in the history of biological science, when great men ravished the globe of its secrets and revolutionized human thought. It was the privilege of the present writer to be personally associated—in many cases intimately so—with the heroes of this story from Lyell onwards, to grow up in their midst and to be thrilled by the daily triumphs of those mighty warriors. Many long years ago he was greeted by Hooker as “a friend and the son of a friend” and it is with those words ringing in his memory that he closes the book of that great man's life.

INDEX.

A.

	Page.
Abbot, Dr. C. G., director, Astrophysical Observatory.....	xii, 20, 88, 108, 121, 185
Abbott, Dr. W. L.....	4, 17, 27, 30, 110, 114
Adams, W. I.....	xi, xii
Account of the rise of navigation (Curtiss).....	127
Adirondack and White Mountains, grasses of.....	9
Advisory Committee for Aeronautics, National.....	2, 113
Advisory Committee on Printing and Publication (Smithsonian).....	101
Agriculture, Secretary of (member of the Institution).....	xi
Aircraft Board.....	2, 113
Aldrich, L. B.....	xii, 21, 83, 84, 85, 87
Allotments for printing.....	15
American families, studies on old.....	10
American Historical Association.....	15, 101
American Indian, Museum of, Heye Foundation.....	27
American Red Cross Hospital at Neuilly.....	3
Anthropological collections, National Museum.....	27
Anthropological studies on old American families.....	10
Appalachian and Ohio valleys, geological work in.....	7
Appropriations.....	5
Arbib, Cavaliere Salvatore.....	29
Army and Navy, United States, researches for the.....	2, 5
Aschemeier, C. R. W.....	31, 115
Assistant secretary of the Institution.....	xi, xii, 110
Astrophysical Observatory.....	xxi, 5, 15, 20, 113
Avery fund.....	4, 103
Avery, Robert Stanton (bequest).....	108
Aviation, experimental work in.....	3

B.

Background of totemism, the (Hopkins).....	573
Bahkmeteff, Boris.....	18
Baker, A. B.....	xii
Baker, Hon. Henry D.....	67
Baker, Newton Diehl, Secretary of War (member of the Institution).....	xi
Bartsch, Dr. Paul.....	xii, 69
Bassler, Dr. R. S.....	xii, 7, 8, 33, 34
Baumann, Gustave.....	29
Beeson, L. W.....	xii
Bell, Alexander Graham (Regent).....	xi, 2, 106
Belote, T. T.....	xii
Bement, C. S.....	33
Benedict, A. C.....	7
Benedict, James E.....	xii

	Page.
Benjamin, Dr. Marcus.....	xii, 100
Bequests.....	3
Bernadou, Mrs. J. B. (bequest).....	29
Berry, Prof. E. W.....	35
(Paleobotany: A sketch of the origin and evolution of floras).....	289
Biological collections, National Museum.....	30
Biological work in North China.....	114
Bird song, sexual selection and (Hawkins).....	461
Bliss, Eleanor (Some problems of international readjustment of mineral supplies as indicated in recent foreign literature).....	251
Boas, Dr. Franz.....	xii, 52
Borneo and Celebes expedition.....	114
Bouvier, E. L. (The psychic life of insects).....	451
Bracchlein, J. G.....	27
Bridgman, Dr. P. W., the experiments of, on the properties of matter when under high pressure (Abbot).....	185
Brockett, Paul.....	xi, 93
Brown, Edward J.....	32
Brown, S. C.....	xii
Bryant, H. S.....	xii
Bushnell, D. I., jr.....	53
Burleson, Albert Sidney, Postmaster General (member of the Institution).....	xi

C.

Caldwell, John.....	11
Carlill, James (Wind power).....	147
Carroll, B. Harvey.....	29
Case, Prof. E. C.....	35
Catalogue of scientific literature, international.....	xii, 1, 5, 15, 22, 94
Cave deposit of Western Maryland, a Pleistocene (Gidley).....	281
Celebes and Borneo expedition.....	114
Celebes expedition.....	4
Chamberlain, Col. Weston P. (History of military medicine and its contribu- tions to science).....	235
Chamberlain fund.....	4, 103
Chancellor of the Institution.....	xi, 2
Chetverikov, S. S. (The fundamental factor of insect evolution).....	441
Chief Justice of the United States (member of the Institution).....	xi, 1, 2, 107, 111
Choate, Charles F., jr. (Regent).....	xi, 2
Chubb, Lawrence S.....	32
Clark, A. Howard, editor of the Institution.....	xi, xii, 15, 101
Clarke, Dr. F. W.....	xii
Clayton, Dr. H. H.....	84
Clements, Gabrielle de V.....	29
Coagulation of albumen by pressure (Bridgman).....	195
Cohn, Prof. Adolphe.....	59
Collections, Bureau of American Ethnology.....	56
Collections, National Museum.....	27
Collins, A. M.....	114
Collins-Garner Congo expedition.....	31, 109, 114
Colorado and Utah, ethnological explorations in.....	12

	Page.
Coloration of tropical fishes, marine camoufleurs and their camoufflage: the present and prospective significance of facts regarding the (Longley).....	475
Commerce, Secretary of (member of the Institution).....	XI
Consolidated fund.....	4
Constitutional league of peace in the Stone Age of America. The league of the Iroquois and its constitution (Hewitt).....	527
Cook, O. F. (Foot-plow agriculture in Peru).....	487
Council of National Defense.....	2, 113
Coville, F. V.	XII
Crawford, J. C.....	XII
Curtiss, R. H. (An account of the rise of navigation).....	127

Dall, Dr. William H.	XII, 91
Daniels, Josephus, Secretary of the Navy (member of the Institution).....	XI
Daughters of the American Revolution, report of.....	101
Degeneracy, the problem of (Tredgold).....	547
Denmark, C. R.....	XII
Dennis, Representative Leonidas.	14
Densmore, Frances.....	53, 56
Director of the Astrophysical Observatory.....	XII, 20, 88, 108, 121, 185
Discovery of helium and what came of it, the (Abbot).....	121
Dorsey, Harry W., chief clerk of the Institution.....	XI
Dyar, Dr. Harrison G.	31

E.

Eakle, Prof. A. S.....	34
Echinoderms, Springer collection of.....	4
Eclipse of the sun, June 8, 1918, observations of.....	5
Editors of the Institution and branches.....	XI, XII, 15, 100, 101
Eddy, the A. R. and M. H. donation.....	18, 39
Ellis Memorial Collection.....	28
Environment and evolution, the direct action of (Kropotkin).....	409
Erskine, Alfred M.....	17, 27
Ethnological explorations in Colorado and Utah.....	12
Ethnology, Bureau of American.....	XII, 1, 5, 12, 15, 19, 112
library.....	55, 92
manuscripts.....	54
publications.....	54, 101
report.....	43
Evans, Victor J.	28, 66
Evolution, environment and, the direct action of (Kropotkin).....	409
Evolution, insect, the fundamental factor of (Chetverikov).....	441
Evolution, irreversible, on the law of (Petronievics).....	429
Exchanges, International.....	XI, 1, 5, 15, 21
report.....	58
Executive Committee of the Board of Regents.....	XI
report of.....	101
Experiments of Dr. P. W. Bridgman on the properties of matter under high pressure (Abbot).....	185
Explorations and researches.....	5, 44

F.	Page.
Fairbanks, Charles Warren (Regent).....	2, 23
Farmer, Moses G.....	3
Farmer, Miss S. J. (bequest).....	3
Ferris, Representative Scott (Regent).....	xi, 2, 111
Fewkes, J. Walter, Chief, Bureau of American Ethnology. xii, 12, 16, 43, 45, 46, 55, 57 (Sun worship of the Hopi Indians).....	493
Finances of the Institution.....	4
Fishes, tropical, the present and prospective significance of facts regarding the coloration of: marine camoufleurs and their camouflagage (Longley).....	475
Flint, J. M.....	91
Foot-plow agriculture in Peru (Cook).....	487
Foreign depositories of United States governmental documents.....	61
Foreign exchange agencies.....	63
Fowle, F. E.....	xii, 20, 21, 83
Frachtenberg, Dr. Leo J.....	51, 57
Freer Art Gallery.....	18, 38, 108, 111
Freer, Charles L.....	39, 108
Freer collection, the Charles L.....	38
Fundamental factor of insect evolution, the (Chetverikov).....	441
Funds.....	4

G.

Garner, R. L.....	114
Gatschet, Dr.....	46, 51
Geological collections, National Museum.....	32
Geological work in the Appalachian and Ohio valleys.....	7
Geological work in central Kentucky.....	8
Geological work in Maryland.....	7
Geological work in the Rocky Mountains.....	6
Gidley, J. W. (A Pleistocene cave deposit of western Maryland).....	281
Gifts.....	4
Gilbert, Chester G.....	xii, 3, 38
Gill, DeLancey.....	xii, 52
Gill, Mrs. M. W.....	70
Gilmore, Charles W.....	271
Goldsmith, J. S.....	xii
Grasses of the Adirondack and White Mountains.....	9
Gray, George (Regent).....	xi, 2, 106, 107
Greene, Representative Frank L. (Regent).....	xi, 2
Gregory, Thomas Watt, Attorney General (member of the Institution).....	xi
Gunnell, Leonard C.....	xii, 96
Gurley, J. G.....	54

H.

Habel fund.....	4
Haeberlin, Dr.....	52
Haiti and Santo Domingo expedition.....	114
Hamilton fund.....	4
Hammell, John F.....	7
Harrington, John P.....	xii, 51
Hawikuh, excavations at.....	44, 112
Hawkins, Chauncey J. (Sexual selection and bird song).....	461
Hay, Dr. O. P.....	35, 91

	Page.
Helium, the discovery of, and what came of it (Abbot).....	121
Henderson, John B. (Regent).....	xi, 2, 107, 111
Hess, F. L.....	32
Hewitt, J. N. B.....	xii, 47
(A constitutional league of peace in the Stone Age of America. The league of the Iroquois and its constitution).....	527
Hewitt, Mrs. Robert.....	30
High pressure, experiments of Dr. P. W. Bridgman on the properties of matter when under (Introductory note—Abbot).....	185
High pressure and five kinds of ice (Bridgman).....	186
Hill, J. H.....	xi
Hillebrand, Dr. W. F.....	34
History of military medicine and its contributions to science (Chamberlain)....	235
History in tools (Petrie).....	563
Hitchcock, A. S.....	9, 31
Hodge, F. W.....	16, 43, 44, 45, 57
Hodgkins fund.....	4, 21, 55, 58, 103, 108, 113
Hollis, Senator Henry French (Regent).....	xi, 2, 107
Hollister, N., superintendent, National Zoological Park.....	xii, 15, 81
Holmes, Dr. William H.....	xii, 52, 91
Hooker, Sir Joseph—a great naturalist (Lankester).....	585
Hopkins, E. Washburn (The background of totemism).....	573
Hough, Dr. Walter.....	xii, 27, 53
Houston, David Franklin, Secretary of Agriculture (member of the Institution). .	xi
Hovenweep National Monument.....	46
Howard, Dr. L. O.....	xii
Hrdlička, Dr. Aleš.....	xii, 3, 10, 11, 91
Hughes alcove.....	3
Hughes, Rev. Bruce (bequest).....	3

I.

Iddings, Dr. J. P.....	34
Income of the Institution.....	5
Indian, the vanishing.....	11
Insect evolution, the fundamental factor of (Chetverikov).....	441
Interior Department.....	12, 19
Public Park Service.....	13
Interior, Secretary of the (member of the Institution).....	xi
International catalogue of scientific literature.....	xii, 1, 5, 15, 22, 94
International exchanges.....	xii, 1, 5, 15, 21
report.....	58
Interparliamentary exchange of official journals.....	63
Irreversible evolution, on the law of (Petronievics).....	429

J.

Jepson, Prof. W. L.....	32
Johnson, U. S. Consul Nelson T.....	33, 110
Joseph, E. S.....	70
Judd, Neil M.....	27, 52

K.

Kelvin, Lord.....	29
Kent, Representative William.....	13
Kentucky, geological work in central.....	8

	Page.
Killip, Ellsworth P.....	31
King, Samuel L.....	11
Knoche, Dr. Walter.....	85
Knowles, W. A.....	xii
Knowlton, Dr. F. H.....	35
Koren, John.....	35
Kramer, A.....	82, 85
Kroeber, Dr. A. L.....	53
Kropotkin, Prince (The direct action of environment and evolution).....	409

L.

Labor, Secretary of (member of the Institution).....	xi
La Flesche, Francis.....	xii, 48, 49, 50
Lane, Franklin Knight, Secretary of the Interior (member of the Institution) ..	xi
Langley Aerodynamical Laboratory.....	108, 113
Langley Field.....	3
Langley flying machine.....	3, 28, 114
Langley, Samuel Pierpont.....	3, 28, 114
pioneer in practical aviation. A tribute (Leffmann).....	157
Lanckester, Sir Ray (A great naturalist—Sir Joseph Hooker).....	585
Lansing, Robert, Secretary of State (member of the Institution).....	xi
La Varre, W. J.....	70
League of the Iroquois and its constitution. A constitutional league of peace in the Stone Age of America (Hewitt).....	527
Leary, Ella.....	xii, 55
Leffmann, Henry (A tribute—Samuel Pierpont Langley: Pioneer in practical aviation).....	157
Lewton, Frederick L.....	xii
Liberty Loan Bonds, U. S. Third.....	5
Libraries of the Institution and branches.....	16, 42, 55, 89
summary of accessions.....	93
Lindgren, Prof. Waldemar.....	34
Lloyd, James T.....	2
Loan exhibitions, National Museum.....	39
Lodge, Senator Henry Cabot (Regent).....	xi, 2, 107, 111
Longley, W. H. (Marine camoufleurs and their camouflage: The present and prospective significance of facts regarding the coloration of tropical fishes)...	475
Loughlin, Dr. G. F.....	34

M.

McAdoo, William Gibbs, Secretary of the Treasury (member of the Institution).	xi
McClellan, Hon. George B.....	29, 109
McKinney, Mrs. Glenn Ford.....	29
McLean, J. P.....	91
Macfarlane, Henry B. F.....	13
Manuscripts, ethnological.....	54
Marine camoufleurs and their camouflage: The present and prospective signifi- cance of facts regarding the coloration of tropical fishes (Longley).....	475
Marshall, Thomas R., Vice President of the United States (member of the Institution).....	xi, 107
Martin, Prof. D. S.....	34
Martin, Dr. J. C.....	33

	Page.
Maryland, geological work in.....	7
Matter when under high pressure, the experiments of Dr. P. W. Bridgman on the properties of (Abbot).....	185
Maxon, W. R.....	xii, 91
Maynard, George C.....	xii, 91
Meetings and congresses in the National Museum.....	40
Members of the Institution.....	xi
Merrill, Dr. George P.....	xii, 16, 33
Mesa Verde National Park.....	12, 45
Metals, electrical resistance of, under pressure (Bridgman).....	200
Michelson, Dr. Truman.....	xii, 50, 51
Military medicine, history of, and its contributions to science (Chamberlain).....	235
Miller, Dr. Dayton C.....	53
Miller, Dr. Gerrit S., jr.....	xii, 91
Millikan, R. A. (Twentieth century physics).....	169
Mineral supplies, some problems of international readjustment of, as indicated in recent foreign literature (Bliss).....	251
Mineral technology, collections representative of, National Museum.....	37
Minerals and Derivatives, Joint Information Board of.....	3
Mooney, James.....	xii, 46
Moore, A. F.....	21, 85
Motter, Dr. M. G.....	91
Mount Wilson Observatory, work at.....	86
Mountaineers of Tennessee.....	10
Muir, John M.....	56
Munroe, Helen.....	54
Museum of the American Indian, Heye Foundation.....	27

N.

National Advisory Committee for Aeronautics.....	2, 113
National Defense, Council of.....	113
National Gallery of Art.....	3, 18, 38, 40, 41, 110
National Lead Co. (donation).....	110
National Museum.....	xii, 1, 2, 3, 5, 15, 16, 41, 109
library.....	42, 90
meetings and congresses in.....	40
publications.....	41, 100
report.....	25
use by Government departments.....	40
National Parks Association.....	14
National Parks Educational Committee.....	13
members of.....	14
National Research Council.....	2, 3
National Zoological Park.....	xii, 1, 2, 5, 15, 19, 112
accessions.....	66
alteration of western boundary.....	127
animals in the collection.....	71
flora of.....	78
important needs.....	79
improvements.....	77
library.....	92
removals.....	70
report.....	66
visitors.....	77

	Page.
Navigation, an account of the rise of (Curtiss).....	127
Navy and Army, United States.....	2, 5
Necrology.....	22
Neuilly, American Red Cross Hospital at.....	3
Nichols, Prof. George E. (Sphagnum moss: war substitute for cotton in absorbent surgical dressings).....	221

O.

Observations, eclipse of the sun, June 8, 1918.....	5
Officials of the Institution.....	xi
Orcutt, C. R.	32

P.

Padgett, Representative Lemuel P. (Regent).....	xi, 1, 2
Paine, R. C.	91
Paleobotany: A sketch of the origin and evolution of floras (Berry).....	289
Palmer, William.....	91
Pennell, Joseph.....	39, 41, 111
Perelma, Ossip.....	18, 59, 110
Permanent Committee, Board of Regents.....	108
Petrie, W. M. Flinders (History in tools).....	563
Petronievics, Branislav (On the law of irreversible evolution).....	429
Phosphorus, two new modifications of (Bridgman).....	195
Physics, twentieth century (Millikan).....	169
Pickering, Director E. C.	86
Pleistocene cave deposit of western Maryland, a (Gidley).....	281
Poore fund, Lucy T. and George W.	4, 103
Postmaster General (member of the Institution).....	xi
President of the United States (member of the Institution).....	xi, 1, 29
Printing allotments.....	15
Printing and publication (advisory committee on).....	15, 101
Problem of degeneracy, the (Tredgold).....	547
Problem of radioactive lead, the (Richards).....	205
Proceedings of the Board of Regents.....	107
Psychic life of insects, the (Bouvier).....	451
Public Park Service, director of.....	13, 46
Publications.....	15, 97

R.

Radioactive lead, the problem of (Richards).....	205
Rathbun, Richard, assistant secretary of the Institution.....	xi, xii, 25, 110
Raven, H. C.	4, 27, 30, 110, 114
Ravenel, W. deC.....	xii, 16, 42
Receipts and disbursements, statement of.....	104
Red Cross, Smithsonian Auxiliary of D. C. Chapter of.....	3
Redfield, William Cox, Secretary of Commerce (member of the Institution).....	xi
Regents of the Institution.....	xi, 1
Reid, Addison T., fund.....	4, 103
Remey, Charles Mason.....	39
Reptile reconstruction in the United States National Museum (Gilmore).....	271
Researches and explorations.....	5, 44
Researches on the structure of the trilobites (Walcott).....	7
Reisser, Dr. C. E.	7

	Page.
Total solar eclipse.....	85
Totemism, the background of (Hopkins).....	573
Townsend, Bvt. Maj. Gen. Edward T.....	29
Treasury Department.....	26
Treasury, Secretary of (member of the Institution).....	16
Tredgold, A. F. (The problem of degeneracy).....	547
Trilobites, researches on the structure of the (Walcott).....	7
Twentieth century physics (Millikan).....	169

V.

Vanderbilt, George W.....	16
Vanderbilt, Mrs. George W.....	16, 90
Vanishing Indian, the.....	11
Vice President of the United States (member of the Institution).....	1, 2

W.

Walcott, Dr. Charles D., Secretary of the Institution.....	III, XI, XII, 1, 3, 6, 7, 32, 34, 42, 43, 57, 65, 81, 88, 91, 93, 96, 101, 107, 109, 110
War activities, National Museum.....	25
War Department.....	3
War Industries Board.....	3
War Risk Insurance, Bureau of.....	16, 26, 111
Ward, Prof. Robert DeC. (Tornadoes of the United States).....	139
Washington, Dr. Henry S.....	34
Weather Bureau, United States (Hodgkins grant).....	108, 113
Webb, Walter F.....	31
Wherry, Dr. Edgar T.....	33
White, Andrew D.....	107
White, Edward Douglass, Chief Justice of the United States (member of the Institution).....	XI, 1, 2, 107, 111
White, David.....	XII
White, Henry (Regent).....	XI, 2, 106, 107, 108, 111
Wiener, Capt. Clarence.....	28
Wilson, Ben.....	67
Wilson, Dr. Herrick E.....	7
Wilson, William Bauchop, Secretary of Labor (member of the Institution)....	XI
Wilson, Woodrow, President of the United States (member of the Institution). XI, 1, 29	
Wind power (Carhill).....	147
Woodman, Rev. Clarence.....	85, 86
Worch, Hugo.....	28

Y.

Yard, Robert Sterling.....	13
----------------------------	----

Z.

Zoological Park, National.....	XII, 1, 2, 5, 15, 19, 112
accessions.....	66
alteration of the western boundary.....	79
animals in the collection.....	71
flora of.....	78
important needs.....	79
library.....	92
removals.....	70
report.....	66
visitors.....	77

